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THE IMPULSE STRENGTH OF SOLID AND GAS-FILLED HIGH VOLTAGE CABLES.

BY

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1. INTRODUCTION.

The tests for checking the quality of extra high voltage cables, particularly the gas-filled type, are not too numerous and the few available are, therefore, most welcome. One of these is the impulse test which measures the impulse strength of an insulation, i.e., the field intensity at which the insulation breaks down, if the applied voltage consists of a single wave the duration of the front of which is of the order of one microsecond. It was deemed advisable to outline a method by means of which the impulse strength of different types of cable insulation could be computed on a physical basis. Such a method, if shown by future tests to be correct, should be a useful guide both in designing cables and in interpreting test results.

In the interest of the general reader it should be recalled that high voltage cables consist essentially of a copper conductor, an insulation of paper impregnated with mineral oil and a lead sheath. The insulation of the gas-filled cable contains, in addition to the impregnant, nitrogen gas of a pressure above atmospheric, in order to minimize the possibility that ionization may take place.

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The computations presented in this paper are in several respects only approximate. It is felt, however, that there are so many uncertainties involved in the theory underlying the method that carrying out an elaborate mathematical analysis on this basis would be inappropriate. It seems better to outline a sketchy analysis first, later as a next step to try to correlate it with experiments, then again to improve the theory, and so on. This procedure appears to be the best guarantee against loss of time spent on elaborate theoretical work that later might prove to be wrong.

2. PRINCIPLES OF COMPUTATION.

The computations are based chiefly on four following assumptions.

(*a*) Impulse breakdown is assumed to be an unstable electronic current, not influenced by ionic constituents already present that in deteriorated areas might lead to thermal instability in case of a-c or d-c application.

While there seems to be general agreement regarding this statement, there is no agreement as yet as to the mechanism and significance of the pre-breakdown currents in liquids as obtained at high field intensities. Some authors think that they are electronic and direct fore-runners of the breakdown process. Accordingly the current-voltage characteristic was derived by Baker and Boltz [1] on the basis of the thermionic theory of Schottky; this characteristic being verified also by Dornte.[2] LePage and DuBridge [3] believe that the electron emission is of a thermo-electric nature and arrive at a somewhat different equation. Other authors think that the pre-breakdown currents are ionic, thus in no direct relation with the breakdown process. The increase of conductivity shown by these currents is supposed to be an analogue of the Schiele-Onsager effect in aqueous solutions. The author of this paper in an early publication [4] expressed the idea of molecular dissociation in high fields qualitatively. Among recent papers along these lines that by Plumley [5] and by Race [6] have to be mentioned.

Because of the fact that pre-breakdown currents occur also in highly purified liquids and because of the decisive influence

of the electrode surface, the electronic emission theory appears the most probable *to date*, and consequently the Baker-Boltz characteristic was selected as representing the current that directly leads to breakdown.

(*b*) It is assumed that the straight line characteristic between the logarithm of current and the square root of field intensity will have to be modified, in taking into account the finite mobility of the negative carriers. This mobility will cause the development of space charges, the weakening of the field behind the space charges, and reduction of the current as compared with the original characteristic. The slower the mobility the more pronounced will be the reduction. Thus, with estimated values for the mobility, the characteristic both for oils and for oil-impregnated paper (solid type cable) can be computed.

(*c*) Breakdown is assumed to occur when a certain limiting current is reached. Beyond this limit instability sets in, and breakdown occurs.

This assumption is not in keeping with the generally accepted view that breakdown occurs when a certain *field* intensity is reached. A certain field intensity is evidently a necessary condition for a breakdown, however, not a sufficient one. There are several instances when stabilizing factors will allow a higher field to persist than under normal conditions, because these factors will tend to reduce the *current*. It is known, for instance, that the breakdown strength of air in a narrow channel is higher than in the open, just because adsorption effects on the walls will limit the current. Thus it can be seen that besides a minimum field strength a current threshold also has to be reached. The situation in cables is exactly the same. If field intensity were the only determining factor, the fact that impregnated paper does not break down at field intensities at which oil alone would break down, would not be explainable. The final breakdown criterion is thus a limiting current. While this current is certainly not a constant for all types of insulating materials, it is reasonable to assume that it is a constant for the group—oil, solid, and gas-filled cable; this group being basically an oil insulation, only modified by paper and gas. It should be added that current as a breakdown criterion is not a new assumption,

it has been considered for solid insulation by Joffe and collaborators.[7]

If now such a current limit is selected, then the values of the dielectric strength for both oil and cable insulation can be read from the current-field strength characteristic.

(*d*) In order to apply the method to the gas-filled cable, the simple assumption is made that the negative current flowing through the cable insulation is multiplied in a butt space according to an electronic Townsend-ionization. By butt spaces are understood the spiral-shaped channels between neighboring turns of each individual layer of paper tapes; in the gas-filled cable these butt spaces are filled with high-pressure nitrogen.

The continuity of the current at the liquid-gas boundary implied by such an assumption must not necessarily be taken literally. It is possible, for instance, that periodic sparks take place in the gas pocket, as was treated theoretically and experimentally by the present author and Philippoff.[8] In such a case the role of the negative current in the liquid would be to destroy the positive surface charge at the liquid-gas boundary; thus restoring the field in the gas and allowing a new spark to strike. Averaged over a given time, such a process will be equivalent to a current flowing through the liquid *and* the gas.

If, then, the current is multiplied in the gas-filled spaces by a Townsend mechanism, then the whole current-voltage characteristic will be raised. With the breakdown criterion as specified under (*c*) the electric strength will thus be lowered by such a mechanism. The effect on the breakdown strength of both the gas pressure and the percentage of radial butt space path can be computed by means of the theory.

All computations will be carried out only for a parallel field, and then applied to a cylindrical cable in the following approximate way. Komives, among others, has shown [9] that it is the maximum field intensity at the conductor that determines the breakdown. Consequently the figures as deduced from the parallel field will be a fair approximation for cables, if interpreted as maximum intensities at the conductor. With fields of only moderate inhomogeneity this procedure is quite usual in designing high voltage apparatus.

3. NUMERICAL RELATIONS UNDERLYING THE COMPUTATION.

The four points discussed qualitatively in Section 2 will now be considered from a quantitative angle.

(*a*) Regarding the cathode-initiated electron stream, several equations were proposed that allow the slope to be calculated theoretically. The question as to which of these equations holds is not yet settled. It was preferred, therefore, to select instead a representative experimental curve as the basis of the computations. Since accurate data on cable oils and copper, aluminum (metalized paper) or carbon (carbon-black paper) are not available, the figures for toluene and nickel electrodes in the presence of oxygen as found by Baker and Boltz were selected. (The electrode surface used being about 0.5 cm ^{2}, the currents were numerically half the current density.) The data of these authors are fairly well represented by the following equation:

$$i = 6e^{0.36\sqrt{F}}, \qquad (1)$$

where i = current density and F = field intensity, both in absolute e.s.u.

(*b*) The electrons generated at the cathode will either exist as free electrons, or be attached to the oil molecules. There is no direct experimental evidence for either of these alternatives; however, it is most unlikely that, with the negative carriers moving as slowly as do the bulky negative ions, breakdown of a paper cable should take place in less than one microsecond. It is quite possible that, even if a more or less large fraction of all electrons is attached to the molecules, this bond will not be too strong, since the hydrocarbon molecules are not electronegative. Thus, while in low fields such charged molecules might move as ions, in high fields the electrons will jump from one molecule to the neighboring one, thus freeing another electron at the opposite end of the molecule which again will jump to the next. In other words, in high fields the mobility of the negative carriers is that of free electrons, just as in gases. While this assumption was made for the numerical calculations, it is realized that it might be subject to alteration in the light of future experimental evidence to the contrary.

The mobility of the negative carriers in oils and cable insulation can be roughly estimated on this basis. Hofmann [10] used the Toepler streak method to determine ionic mobilities in toluene and obtained values of the order of 10^{-1} absolute e.s.u. This would correspond to a value of 10^{-3} in oils. The present author [11] evaluated ion mobilities in oil from charging current data, and arrived at a value of 10^{-4}, in fair agreement with the value just mentioned. We know, on the other hand, that the ratio of electronic to ionic mobility in gases is of the order $10^3 : 1$. Using the same ratio, 10^{-1} absolute e.s.u. is obtained as the order of the electronic mobility in oils.

The ratio of the mobility in oil and oil-impregnated paper can be estimated from data on the decrease of conductivity

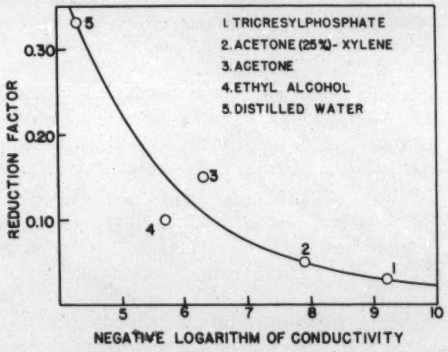

FIG. 1. Reduction of conductivity of a liquid in the presence of medium porosity paper as a function of specific conductivity of the liquid.

of liquids in the presence of paper. Emanueli [12] observed a considerable decrease in the conductivity of insulating oils plus paper, compared with that of oil alone. The present author has some as yet unpublished data referring to semi-conducting liquids and cable paper of medium porosity. A few of these data are shown in Fig. 1, referring to five different liquids. The abscissae are the logarithms of the specific conductivity of the liquid, and the ordinates are the reduction

ratios as caused by the paper. The effect of the paper increases (reduction ratio decreases) with decreasing conductivity, the ratio being about 1 : 30 for a conductivity of 10^{-10} mhos./cm.

The decrease in conductivity observed in these cases is due in part to the decreased effective cross-sectional area between the electrodes if cable paper is present. The value of this reduction ratio can be estimated as about 1 : 3. Another appreciable part, however, can be accounted for only by the decreased mobility due to the adsorption forces of the cellulose fibers. The role of the adsorbed ions must be relatively greater as the total ion concentration becomes lower—a fact brought out by Fig. 1.

This effect is certainly complex; part of the ions will be adsorbed by the cellulose and move as adsorbed particles along the fibers, another part will be only under the influence of attraction forces reaching farther into the liquid. As long as a real analysis of this effect is not possible, it might be as well to work with a composite mobility, this being the equivalent of several overlapping mechanisms. In the light of the above quoted figures the ratio of the mobilities in oil and oil-paper was estimated to be 1 : 10, giving a value 10^{-2} e.s.u. for electrons in the presence of medium porosity paper. It is realized that this derived order of magnitude needs more direct experimental confirmation.

(*c*) Regarding the value of the limiting current, estimates can be made on the basis of experimental observations on liquids and gases. The measurements by Baker and Boltz [1] on characteristics in toluene were made up to around 10^{-5} amp./cm.^{2} current density. Beyond this magnitude instability sets in. This would correspond to an order of 10^{-4} amp./cm.^{2} for the limiting current. The same value can be assumed according to the quoted paper by Race.[6] He measured prebreakdown currents in mineral oil and toluene and registered current densities of the order of 10^{-4} or 10^{-3} amp./cm.^{2}. The corresponding limits in polystyrene and polyvinyl formal appeared to be lower.

The correctness of this estimate is strengthened by data of the present author on the glow-loudspeaker,[13] according to which the corona current in air could be raised up to about

1 ma across a surface, facing the wires, of the order of 100 cm.^{2}, agreeing with the value for liquids as just mentioned. Here again the highest possible stationary current density seems to be 10^{-5} amp./cm.^{2}, and thus 10^{-4} amp./cm.^{2} is the order at which breakdown occurs.

(*d*) As to the ionization in gas-filled butt spaces, the Townsend mechanism was considered as being limited to ionization by electrons. The effect of positive ions is not so much an ionization in the gas phase as a secondary effect upon the cathode; thus they cannot generally play a role in a butt space situated between layers. The increase of the current takes place according to the equation

$$i = i_0 e^{\alpha b}, \tag{2}$$

where b = depth of butt space and α = ionization coefficient of electrons. Regarding the values for this latter, equations given by VerPlanck [14] were used. If F denotes the field strength in kv./cm. and p the pressure in atmospheres, then we have:

for F/p up to 25.8

$$\alpha/p = 1.67 \times 10^{-5} e^{0.47 F/p}, \tag{3}$$

for F/p between 25.8 and 78.7

$$\alpha/p = 0.166(F/p - 21.5)^2, \tag{3a}$$

and for F/p between 78.7 and 200

$$\alpha/p = 19(F/p - 50). \tag{3b}$$

As stated at the end of Section 2, we approximate a cable as having a parallel field distribution in the neighborhood of the conductor. In other words, if this neighboring layer breaks down, the process cannot be localized, and the whole cable fails. The question now is—what is the approximate thickness of such a layer. The order of 0.1 mm. (thickness of one layer of paper) is certainly too low, since it is known that ionization in voids, which are often of the order of the paper thickness, can take place without failure of the cable. Since the total insulation thickness (about 1 to 2 cm.) is too large, as just pointed out, the geometric average ($\sim$ 1 mm.) will be the right order of magnitude. A value of 0.2 cm.

has been selected for the following numerical computations. The field intensity within these first two millimeters is practically the same as that at the conductor surface, justifying the use of equations for a parallel field.

It should be added here that the foregoing consideration is strictly valid only if the conductor is negative. But the difference with a positive conductor is probably not as great as might be expected, because, if the polarity is positive, the negative current starts from the sheath and the carriers will gradually enter fields of increasing intensity, thus the whole radial path will have to be considered. As a result, the emission current is lower but the reduction of the current due to space charges will be much less pronounced for positive than for negative polarity of the wave. Consequently the breakdown voltage with positive polarity will not be too different from that with negative polarity. Existing data show an increase of about 10 per cent.[14a]

4. NUMERICAL COMPUTATIONS.

Oil and solid type cable. In the following paragraphs the current-voltage characteristic in the presence of space charge will be computed. Let us take a plane condenser of unit cross-sectional area and a separation a. The negative space charge density generally varies in the direction of a, but as a simplification it is taken as constant.

The applied average field intensity (voltage divided by a) is F_a, and we seek the field intensity F_c as present at the cathode. The intensity at the anode is the sum of F_c and that due to the space charge density ρ, i.e., $F_c + 4\pi\rho a/\epsilon$ (where ϵ = dielectric constant). The average field intensity is then $F_c + 2\pi\rho a/\epsilon$, and this expression can be identified with F_a. Thus we have

$$F_c = F_a - 2\pi\rho a/\epsilon. \tag{4}$$

If F_c instead of F is put into Eq. (1), the current density in the presence of a space charge density ρ is obtained. In equilibrium the current found by this expression must equal that flowing across the insulation, i.e. $\rho m F_a$, where m = mobility of electrons. Thus

$$6e^{0.36\sqrt{F_a - 2\pi\rho a/\epsilon}} = \rho m F_a, \tag{5}$$

from which ρ and then the current density itself can be computed. Before proceeding, the considerable simplifications in deriving Eq. (5) should be emphasized. In a rigorous treatment one has to start from partial differential equations with current and space charge as variables dependent on time and the space coördinate. These equations then have to be integrated with regard to time and the space coördinate. In Section 1 it was explained that as a first step such an elaborate calculation is not advisable. One peculiar feature of Eq. (5) is that an equilibrium condition has been assumed, thus the time does not occur in it explicitly. The rigorous solution must contain the time as well, in keeping with observations that the impulse strength varies (decreases) with increasing time lag. Our approximate solution is likely to yield results valid for somewhat longer time lags.

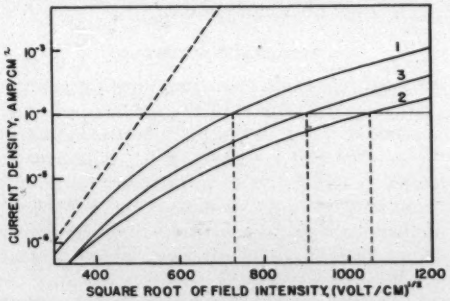

FIG. 2. Current density *vs.* field intensity characteristics for the determination of impulse strength.

1. insulating oil
2. solid type cable
3. gas-filled cable

In evaluating Eq. (5) we used $a = 0.2$ cm., $\epsilon = 2.3$ for oil and 3.6 for cable insulation, and $m = 3 \times 10^{-4}$ cm./sec. per v./cm. for oil and 3×10^{-5} for cable insulation. F_a, the average field intensity, is the independent variable, for each value of which ρ and the current density are computed. The result is shown in Fig. 2, where the abscissæ are square

roots of the field intensity in volt/cm. and the ordinates are current densities in amp./cm^2. The dotted line is the characteristic corresponding to Eq. (1). Curve 1 is for oil and Curve 2 is for the fully impregnated solid type cable. Selecting 10^{-4} amp./cm.^{2} as the limiting current at which instability sets in, the breakdown values (abscissæ corresponding to an ordinate 10^{-4}) are: for oil, 530 kv./cm. = 1350 v./mil.; and for cable, 1120 kv./cm. = 2850 v./mil.

These values can now be checked with available experimental figures. For oil a recent paper by Sorensen [15] on the surge breakdown of oil can be consulted. In keeping with what has been said on the time lag, Sorensen's limiting values (for time lags above 10μ sec.) should be taken. This value for 1" electrodes and 1/2" spacings is 470 kv. This corresponds to an average field of 375 kv./cm. In order to get the field at the electrode, this figure must be divided by 0.73 which is the so-called "utilization factor" [16] for that electrode arrangement. This gives 515 kv./cm. = 1300 v./mil. The agreement with the computed value is satisfactory, the actual coincidence of the two figures is, of course, fortuitous.

For cable insulation we do not possess values corresponding to time lags of 10μ sec. and higher. The breakdown in cable generally occurs at the front of the wave, contrary to that in oils, which occurs at the tail. The usual steep waves are therefore not quite suitable for ascertaining the effect of the time lag upon the impulse strength and the data in the literature refer only to time lags of the order 1μ sec. These data should then be a little higher than our computed values. This is indeed the case: Komives [4] states a value of 3300 v./mil. as obtainable for solid cables, a value in fair agreement with, although a little higher than, our computed value of 2850. The agreement for both oil and cable, however, should be valued as one of order of magnitude only, since the estimates for mobilities, limiting currents, etc., are also correct only as to order of magnitude and not as to actual value.

Gas-filled Cable.—The previous calculation can be extended to cover gas pockets in gas-filled cables. The result will evidently depend on the actual distribution of the gas-filled butt spaces in a radial direction starting from the conductor along a distance a. Instead of a calculation on a necessarily

statistical basis a simplified picture will be used by taking an arbitrary distribution and deriving from it an approximate formula. Since the chief influence of the gap is ionization within the gap, its actual location will have only a secondary effect on the result.

The arbitrary distribution is shown in Fig. 3. The idea underlying this distribution is that the whole gas-filled path,

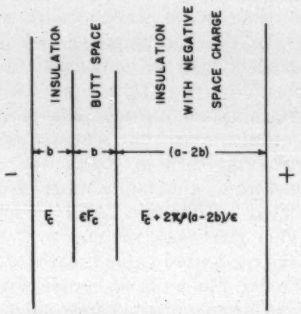

FIG. 3. Assumed distribution of butt space in cable insulation of thickness a near the conductor.

whether comprising one or several butt spaces, is lumped into one gap of spacing b, b/a being the ratio of radially aligned butt spaces to the insulation thickness. It is further assumed that this gap is separated from the conductor by an insulation layer of the same width b. The rest of the insulation in which the space charge is located has then a width $(a - 2b)$.

If the field intensity at the cathode is F_c, then the field in the gap is ϵF_c and the field past the gap $F_c + 2\pi\rho(a - 2b)/\epsilon$, deduced like that for the gas-free insulation. If the average field is F_a, we then have the equation

$$F_c b + \epsilon F_c b + F_c(a - 2b) + 2\pi\rho(a - 2b)^2/\epsilon = F_a a, \quad (6)$$

from which

$$F_c = \frac{F_a a}{a + (\epsilon - 1)b} - \frac{2\pi\rho(a - 2b)^2}{\epsilon[a + (\epsilon - 1)b]}. \quad (7)$$

The current density is now obtained by combining Eq. (1) and (2) as representing a combined action of electronic emission and gaseous ionization, and this current again is taken as equal to the current flowing in the space charge region. Thus

$$6e^{0.36\sqrt{F_c}+\alpha b} = \rho m[F_c + 2\pi\rho(a - 2b)/\epsilon] \qquad (8)$$

with the addition that α is computed from Eq. (3) as a function of the pressure p and the field ϵF_c for F.

Eq. (7) and (8) were used in computing the characteristics for gas-filled cables discussed in the next few paragraphs, $\epsilon = 3.6$ and $a = 0.2$ being used. Parameters of the equations are the gas pressure p and the gap width b. The independent variable is again F_a and the two dependent variables, ρ and F_c, are then computed from Eq. (7) and (8), thus obtaining the current density as either side of Eq. (8).

One particular characteristic is plotted as Curve 3 on Fig. 2. This refers to a gas-filled cable of 200 lb. per sq. in. gage pressure, a butt space ratio $b/a = 10$ per cent., and paper of medium porosity. The curve merges with that for solid cables at low fields, since there is no ionization in the gas phase at these field intensities. The impulse strength for longer time lags is 905 kv./cm. = 2100 v./mil., as compared with 2850 for the solid cable. The ratio, in per cent., between the two values is 74 and it is likely that the ratio is approximately independent of the time lag. Thus for 1μ sec. time lag with 3300 v./mil. for the solid cable, the value for the gas pressure cable will be 2450 v./mil. It is to be expected that this value will be still higher for a cable made with supercalendered paper (lower mobility of negative carriers).

This last figure can be compared with experimental data, obtained by Faucett et al [17] on gas-filled cables. The average maximum gradient from six of their samples, of 450 and 385 mils insulation thickness, is 2650 v./mil., in reasonable agreement with our figure.

A few other characteristics were obtained for different pressures and butt space percentages, and the impulse strengths obtained (for longer time lags) are shown in Fig. 4. The right hand scale of the ordinate shows the percentage figures, that for the solid cable being taken as 100. The

change with pressure (Curve 1, scale of abscissa on top) is only moderate around 200 lb., but, of course, if the pressure drops to atmospheric, the impulse strength becomes fairly low (1450 v./mil.).

The change with butt space percentage (Curve 2, scale of abscissa at bottom) is quite appreciable. While for 10 per cent. alignment, i.e., 1 butt space for 10 paper layers, the

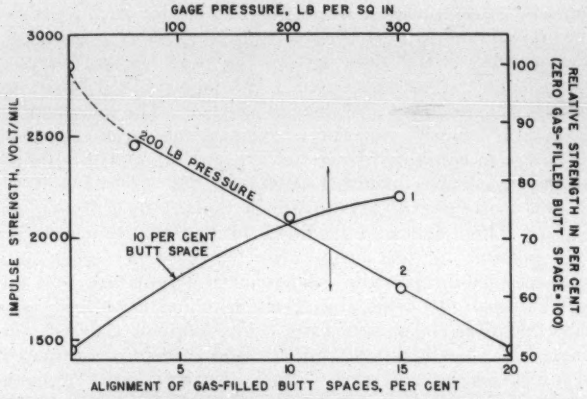

FIG. 4. Impulse strength of gas-filled cables as a function of (1) gage pressure, (2) butt space alignment.

strength is 2100 v./mil., the value drops to 1750 for 15 per cent. alignment and to 1450 for 20 per cent., i.e., 2 butt spaces for 10 paper layers.

In finishing, it should be repeated that if experimental checks of the theory seem encouraging, it will then be worth while to refine, step by step, the approximate computations presented. A more rigorous theory will account, among other things, for time lag and polarity effects, which were entirely neglected in this paper.

SUMMARY.

A method is presented that allows the computation of the impulse strength of insulating oil and of solid and gas-

filled cables. The principle of the calculation is that breakdown is initiated by currents due to an electronic emission from the cathode; in gas-filled cables these currents are increased by means of gaseous ionization in the butt spaces. Approximate equations are deduced and numerical impulse strength values for insulating oil and solid cable computed, resulting in fair agreement with experimental observations. Extending the equations to gas-filled cables, numerical impulse data for varying gas pressure and for varying radial butt-space alignment are evaluated.

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Single Crystals—Metallurgical Paradox.—FRANK T. SISCO, in his article on previews of tomorrow's metallurgy in *Mining and Metallurgy*, Vol. 23, No. 430, states that an interesting subject for tomorrow's research in physical metallurgy is that of single crystals. These unique materials have been more or less neglected in the research laboratories of the United States; most of the scant knowledge we have of single crystals was obtained in England and Germany. Although more data are available today than ten or even five years ago, many complexities remain which, when cleared up, should help greatly in understanding the polycrystalline aggregates that are our industrial metals and alloys. For example, it is readily understandable why single crystals slip under stress along certain preferred planes of weakness, but it is not so clear why slip does not take place with equal ease on all parallel planes but occurs on certain arbitrary planes spaced at considerable but variable distances from each other. In addition, it would be interesting to know why, when a single crystal is loaded and maintained under load for some time, slip takes place discontinuously—by fits and jerks as it were—in both time and place. These two phenomena are not what one would expect from perfect single crystals. In general, the properties of single crystals are well known; their yield strength is so low that usually the crystal begins to elongate at a stress only one hundredth of that necessary to cause comparable slip in polycrystalline material. In addition, and paradoxically, the amount of strain-hardening at atmospheric temperature is much greater in single crystals than in polycrystalline metals, especially if the metal is one—like copper, silver, or gold—that melts at a comparatively high temperature. So far, the only explanation for these paradoxes is that the crystal lattice of most pure metals is not perfect but contains groups of atoms that are "misfits"; in other words, they are not in line with their neighbors. In some planes these groups of misfit atoms act as keys and prevent slip or cause slip to proceed by jerks instead of smoothly. This explanation leaves much to be desired. Although the study of single crystals may seem somewhat academic and far removed from the rolling mill, forge shop, or the wiredrawing block, these structural entities undoubtedly carry within themselves the secret of metallic softness and metallic strength and are, therefore, worthy of considerably more attention than they have received.

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A GENERAL METHOD OF APPROXIMATION TO THE INFLUENCE FUNCTION OF AN ELASTIC SYSTEM.

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The function which expresses the deflection of an elastic system at any point due to a unit load at any other point is called the Influence Function or Green's Function. The determination of this function in such cases as the string tightly stretched between two points, or the hanging rope, or the uniform beam under a variety of boundary conditions is a fairly simple matter. However, in problems concerning the bending of plates the function is either unknown or is expressed in a form unsuitable for computation. It is with particular reference to the latter class of problems that this paper is directed.

We present here a method for obtaining approximate numerical values of the influence function at a number of points directly from the differential equation and the boundary conditions, without having to integrate the differential equation. It is a method based on finite differences but differs from that of Marcus [1] in that we do not have to solve a system of linear equations which have been set up for a particular loading.

The starting point of our solution is the differential equation for the free vibration of the system. A uniform network is laid over the system, and at each point of the network which undergoes a displacement, the differential equation is replaced by a difference equation. Boundary conditions are introduced in the writing of the difference equations in the appropriate manner whenever a boundary point is involved in an equation. This leads to a system of linear homogeneous equations, the determinant of which set equal to zero is the characteristic equation expressing the necessary condition for a non-trivial solution. The roots of this equation are approximations to the first n natural frequencies or characteristic values of the system, where n is the number of network points

which undergo displacement. If we form the matrix of the coefficients of the terms of this system of linear equations and find its reciprocal, the element which occupies the jth row and kth column in the inverse matrix is the displacement of the system at point j in the network due to a unit load at point k.

GENERAL THEORY.

The differential equation for the free vibrations of a system of one dimensional extent is of the form

$$L(W) \pm mp^2W = 0, \tag{1}$$

where L is the linear differential operator

$$g_0 \frac{d^n}{dx^n} + g_1 \frac{d^{n-1}}{dx^{n-1}} + \cdots g_{n-1} \frac{d}{dx}$$

W is the displacement of the system at any point x,
m the mass per unit length, and
p the natural frequency.

The g's may be constants or functions of x. We replace this differential equation by a difference equation at each point of the network which undergoes a displacement. This is done in the following way: construct a uniform network and let h be the width of the mesh. The first and second derivatives at point x_k are respectively [1]

$$\left(\frac{dW}{dx}\right)_k = \frac{W_{k+1} - W_{k-1}}{2h},$$

$$\left(\frac{d^2W}{dx^2}\right)_k = \frac{W_{k+1} - 2W_k + W_{k-1}}{h^2}.$$

The higher derivatives are given by similar expressions. Place these expressions for the derivatives into equation (1). This leads to a system of linear equations of the form

$$\begin{aligned}
&(a_{11} - m_1hp^2)W_1 + a_{12}W_2 + \cdots + a_{1n}W_n = 0 \\
&a_{21}W_1 + (a_{22} - m_2hp^2)W_2 + \cdots + a_{2n}W_n = 0 \\
&\quad\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\
&a_{n1}W_1 + \cdots + (a_{nn} - m_nhp^2)W_n = 0
\end{aligned} \tag{2}$$

where m_k is the mass per unit length at point k of the network and the a's are constants. The characteristic or frequency equation is

$$\begin{vmatrix} (b_{11} - p^2) & b_{12} & \cdots & b_{1n} \\ b_{21} & (b_{22} - p^2) & \cdots & b_{2n} \\ \cdot & & & \\ \cdot & & & \\ \cdot & & & \\ b_{n1} & & \cdots & (b_{nn} - p^2) \end{vmatrix} = 0, \qquad (3)$$

where $b_{jk} = \dfrac{a_{jk}}{hm_j}$. This equation may be written in the compact form

$$|B - p^2 I| = 0, \qquad (3a)$$

where I is the unit matrix and B is the matrix

$$\begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & & \cdots & b_{2n} \\ \cdot & & & \\ \cdot & & & \\ \cdot & & & \\ b_{n1} & & \cdots & b_{nn} \end{bmatrix}. \qquad (4)$$

The n roots of equation (3) are approximations to the first n natural frequencies of the vibrating system. Associated with each characteristic value is a characteristic function showing the general shape of the system when vibrating in the corresponding natural mode.

This characteristic function satisfies the integral equation [2]

$$W(x) = p^2 \int_0^l G(x, s) W(s) m(s) ds, \qquad (5)$$

where $G(x, s)$ is the influence function expressing the deflection of the system at any point x due to a unit load at point s. By dividing the domain over which the integral is taken, in the same manner as before, and replacing the integral by a

sum, we obtain the following system of linear equations:

$$\begin{aligned}
\frac{1}{p^2} W_1 &= G_{11} W_1 m_1 h + G_{12} W_2 m_2 h + \cdots + G_{1n} W_n m_n h \\
&\cdot \\
&\cdot \\
&\cdot \\
\frac{1}{p^2} W_n &= G_{n1} W_1 m_1 h + \cdots + G_{nn} W_n m_n h.
\end{aligned} \tag{6}$$

Here G_{jk} is used to designate $G(x_j, x_k)$ and is referred to as an influence coefficient. The characteristic equation of this system is

$$\begin{vmatrix}
\left(C_{11} - \frac{1}{p^2}\right) & C_{12} & \cdots & C_{1n} \\
C_{21} & \left(C_{22} - \frac{1}{p^2}\right) & \cdots & C_{2n} \\
\cdot & & & \\
\cdot & & & \\
\cdot & & & \\
C_{n1} & \cdots & & \left(C_{nn} - \frac{1}{p^2}\right)
\end{vmatrix} = 0, \tag{7}$$

where $C_{jk} = G_{jk} m_k h$. The solutions of equation (7) give us the reciprocals of the first n natural frequencies of the system.

In matrix form this characteristic equation may be written

$$\left| C - \frac{1}{p^2} I \right| = 0, \tag{7a}$$

where

$$C = \begin{pmatrix}
C_{11} & \cdots & C_{1n} \\
\cdot & & \\
\cdot & & \\
\cdot & & \\
C_{n1} & \cdots & C_{nn}
\end{pmatrix}. \tag{8}$$

Comparing equation (7a) with previous equation (3a), we see that B and C must be reciprocal matrices. This follows from the theorem that the characteristic values of the inverse matrix are the reciprocals of the characteristic values of the original matrix.[3]

We now proceed to establish an important connection between matrix B, as previously defined, and that matrix whose elements involve the influence coefficients. This is done by writing B as a product of two matrices in the following manner:

$$B = \begin{pmatrix} \frac{a_{11}}{hm_1} & \frac{a_{12}}{hm_1} & \cdots & \frac{a_{1n}}{hm_1} \\ \frac{a_{21}}{hm_2} & \frac{a_{22}}{hm_2} & \cdots & \frac{a_{2n}}{hm_2} \\ \cdot & & & \\ \cdot & & & \\ \cdot & & & \\ \frac{a_{n1}}{hm_n} & & \cdots & \frac{a_{nn}}{hm_n} \end{pmatrix}$$

$$= \begin{pmatrix} \frac{\mathrm{I}}{hm_1} & \mathrm{o} & \mathrm{o} & \cdots & \mathrm{o} \\ \mathrm{o} & \frac{\mathrm{I}}{hm_2} & \mathrm{o} & \cdots & \mathrm{o} \\ \cdot & & & & \\ \cdot & & & & \\ \cdot & & & & \\ \mathrm{o} & \mathrm{o} & & \cdots & \frac{\mathrm{I}}{hm_n} \end{pmatrix} \begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdot & & & \\ \cdot & & & \\ \cdot & & & \\ a_{n1} & & \cdots & a_{nn} \end{pmatrix} \tag{9}$$

Let M and A respectively represent these two matrices. Then in matrix notation

$$B = MA$$

and

$$B^{-1} = A^{-1}M^{-1} = C$$

since B and C are reciprocal matrices.

C itself may also be written as the product of two matrices; viz.,

$$C = \begin{pmatrix} G_{11} & \cdots & G_{1n} \\ \cdot & & \\ \cdot & & \\ \cdot & & \\ G_{n1} & & G_{nn} \end{pmatrix} \begin{pmatrix} hm_1 & \mathrm{o} & \cdots & \mathrm{o} \\ \mathrm{o} & hm_2 & \cdots & \mathrm{o} \\ \cdot & & & \\ \cdot & & & \\ \mathrm{o} & \mathrm{o} & \cdots & hm_n \end{pmatrix}.$$

Let the first of these be designated by the letter G. The second matrix is M^{-1} since it is a diagonal matrix whose elements are the reciprocals of the corresponding elements of diagonal matrix M.

Now $$B^{-1} = A^{-1}M^{-1}$$

and $$C = B^{-1} = GM^{-1}.$$

Thus $$A^{-1} = G.$$

This relation shows us that the influence numbers (viz., the elements of matrix G) whose determination is our primary object, are simply the elements of the matrix reciprocal to A. Since A itself is always readily set up from the difference equations which replace the differential equation, the determination of these influence numbers resolves itself into the determination of the matrix reciprocal to A. This reciprocal matrix may be obtained by any one of several methods.[4]

The ease and applicability of this general method is now demonstrated by applying it to several practical problems whose numerical solution is already known. It should be noted that a good approximation to the correct solution can be obtained, even with the use of few network points.

EXAMPLE I.

A Uniform Beam Simply Supported at Both Ends, Fig. 1.

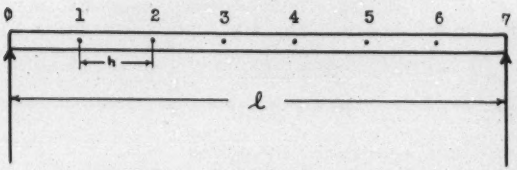

FIG. 1.

Our starting point is the differential equation for any freely vibrating beam.[5] This takes the form

$$\frac{d^2}{dx^2}\left(EI \frac{d^2w}{dx^2} \right) = mp^2w,$$

where w is the deflection at any point,

E the modulus of elasticity,
I the moment of inertia of the cross section,
m the mass per unit length,
and p the natural frequency.

This equation of the fourth order may be replaced by two second order differential equations; viz.,

$$\begin{cases} u = EI\dfrac{d^2w}{dx^2}, \\ \dfrac{d^2u}{dx^2} = mp^2w. \end{cases}$$

At a simply supported end, the deflection w and the moment M are zero. Hence in the problem under consideration the boundary conditions are

$$w(0) = w(l) = 0,$$
$$u(0) = u(l) = 0.$$

The difference equations corresponding to the pair of differential equations are

$$\begin{cases} \dfrac{EI}{h^2}(w_2 - 2w_1 + w_0) = u_1 \\ \dfrac{EI}{h^2}(w_3 - 2w_2 + w_1) = u_2 \\ \qquad\qquad . \\ \qquad\qquad . \\ \qquad\qquad . \\ \qquad \text{etc.} \end{cases} \tag{10}$$

and

$$\begin{cases} \dfrac{I}{h^2}(u_2 - 2u_1 + u_0) = mp^2w_1 \\ \dfrac{I}{h^2}(u_3 - 2u_2 + u_1) = mp^2w_2 \\ \qquad\qquad . \\ \qquad\qquad . \\ \qquad\qquad . \\ \qquad \text{etc.} \end{cases} \tag{11}$$

where w_k and u_k are respectively the deflection and moment at point k of the network.

Replacing the u's in equations (11) by their values from (10), we obtain the following system of equations

$$\begin{aligned} 5w_1 - 4w_2 + w_3 &= \frac{mp^2h^4}{EI} w_1 \\ -4w_1 + 6w_2 - 4w_3 + w_4 &= \frac{mp^2h^4}{EI} w_2 \\ &\cdot \\ &\cdot \\ &\cdot \\ &\text{etc.} \end{aligned} \tag{12}$$

If we restrict the number of network points undergoing displacement to six, we obtain for the matrix A as previously defined in equation (9)

$$\frac{EI}{h^3} \begin{pmatrix} 5 & -4 & 1 & 0 & 0 & 0 \\ -4 & 6 & -4 & 1 & 0 & 0 \\ 1 & -4 & 6 & -4 & 1 & 0 \\ 0 & 1 & -4 & 6 & -4 & 1 \\ 0 & 0 & 1 & -4 & 6 & -4 \\ 0 & 0 & 0 & 1 & -4 & 5 \end{pmatrix}.$$

The inverse of A, which has been shown to be the influence matrix G, is found to be

$$G = \frac{h^3}{EI} \begin{pmatrix} 1.857 & 2.857 & 3.143 & 2.857 & 2.143 & 1.143 \\ 2.857 & 5.000 & 5.714 & 5.286 & 4.000 & 2.143 \\ 3.143 & 5.714 & 7.143 & 6.857 & 5.286 & 2.857 \\ 2.857 & 5.286 & 6.857 & 7.143 & 5.714 & 3.143 \\ 2.143 & 4.000 & 5.286 & 5.714 & 5.000 & 2.857 \\ 1.143 & 2.143 & 2.857 & 3.143 & 2.857 & 1.857 \end{pmatrix}. \tag{13}$$

Equation (13) gives the desired approximation to the influence function. For example, the element in the kth row and rth column multiplied by $\frac{h^3}{EI}$, is the deflection at point k of the network due to a unit load at point r.

The exact solution for the deflections at our network points obtained from the usual formula of beam theory is

$$\frac{h^3}{EI}\begin{pmatrix} 1.715 & 2.74 & 3.05 & 2.78 & 2.10 & 1.12 \\ 2.74 & 4.76 & 5.52 & 5.14 & 3.90 & 2.10 \\ 3.05 & 5.52 & 6.86 & 6.64 & 5.14 & 2.78 \\ 2.78 & 5.14 & 6.64 & 6.86 & 5.52 & 3.05 \\ 2.10 & 3.90 & 5.14 & 5.52 & 4.76 & 2.74 \\ 1.12 & 2.10 & 2.78 & 3.05 & 2.74 & 1.715 \end{pmatrix}.$$

EXAMPLE II.

A Square Plate Simply Supported Around the Edges, Fig. 2.

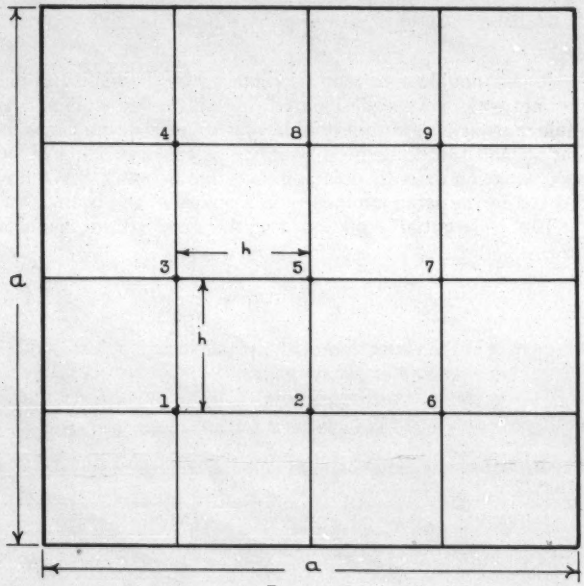

FIG. 2.

Comparing the exact deflections with the deflections found by use of our approximate method, we see that the maximum error is about 4.1 per cent.

In the case of a body, such as a plate, having two dimensional extent, the integral equation for the deflection of the body in a characteristic or natural mode of vibration is given by

$$w(x, y) = p^2 \int\int G(x, y; \xi, \eta) w(\xi, \eta) m(\xi, \eta) d\xi d\eta,$$

where $G(x, y; \xi, \eta)$ is the deflection of the system at (x, y) due to a unit load at (ξ, η) and m is the mass per unit area. When this integral is replaced by a double sum over a uniform network $\Delta x = \Delta y = h$, we obtain

$$w_{r,s} = p^2 \sum_j \sum_k G_{r,s;j,k} w_{j,k} m_{j,k} h^2.$$

Now, this double sum may be replaced by a single sum and the network points designated by single subscripts. An analogous change from a double sum to a single sum may be made when the differential equation is replaced by a difference equation at each point of the same network. We now proceed in the same manner as in the case of the beam.

The differential equation for the free vibrations of a plate is [5]

$$\nabla^4 w = \frac{m p^2 w}{D}, \tag{14}$$

where w is the deflection of the plate at any point,
m is the mass per unit area,
p the natural frequency,
and D the flexural rigidity.

Equation (14) is replaced by two equations of the second order

$$\nabla^2 w = u,$$

$$\nabla^2 u = \frac{m p^2 w}{D}.$$

The boundary conditions are w and u both zero along the edges.

A uniform network as shown in Figure 2 is set over the plate and at each network point, the differential equations are

replaced by the corresponding difference equations in the following manner. At the point r of the network $\nabla^2 w$ and $\nabla^2 u$ are replaced by

$$\nabla^2 w = \frac{1}{h^2}(w_i + w_j + w_k + w_l - 4w_r),$$

$$\nabla^2 u = \frac{1}{h^2}(u_i + u_j + u_k + u_l - 4u_r),$$

where i, j, k, and l are neighboring network points as illustrated in Figure 3. We obtain a system of linear homogeneous equations in the w's by writing the appropriate equations at each network joint and eliminating the u's. The matrix A as previously defined is now found to be

$$\frac{D}{h^2}\begin{pmatrix} 18 & -8 & -8 & 1 & 2 & 1 & 0 & 0 & 0 \\ -8 & 19 & 2 & 0 & -8 & -8 & 2 & 1 & 0 \\ -8 & 2 & 19 & -8 & -8 & 0 & 1 & 2 & 0 \\ 1 & 0 & -8 & 18 & 2 & 0 & 0 & -8 & 1 \\ 2 & -8 & -8 & 2 & 20 & 2 & -8 & -8 & 2 \\ 1 & -8 & 0 & 0 & 2 & 18 & -8 & 0 & 1 \\ 0 & 2 & 1 & 0 & -8 & -8 & 19 & 2 & -8 \\ 0 & 1 & 2 & -8 & -8 & 0 & 2 & 19 & -8 \\ 0 & 0 & 0 & 1 & 2 & 1 & -8 & -8 & 18 \end{pmatrix}.$$

The matrix reciprocal to A, which has been previously shown to be the same as G, the matrix of the influence coefficients, is

$$G = \frac{h^2}{D}\begin{bmatrix} 0.1167 & 0.0829 & 0.0829 & 0.0391 & 0.0782 & 0.0391 & 0.0421 & 0.0421 & 0.0244 \\ 0.0829 & 0.1239 & 0.0781 & 0.0421 & 0.1250 & 0.0829 & 0.0781 & 0.0322 & 0.0421 \\ 0.0829 & 0.0781 & 0.1239 & 0.0829 & 0.1250 & 0.0421 & 0.0322 & 0.0781 & 0.0421 \\ 0.0391 & 0.0421 & 0.0829 & 0.1167 & 0.0782 & 0.0244 & 0.0421 & 0.0829 & 0.0391 \\ 0.0782 & 0.1250 & 0.1250 & 0.0782 & 0.2141 & 0.0782 & 0.1250 & 0.1250 & 0.0782 \\ 0.0391 & 0.0829 & 0.0421 & 0.0244 & 0.0782 & 0.1167 & 0.0829 & 0.0421 & 0.0391 \\ 0.0421 & 0.0781 & 0.0322 & 0.0421 & 0.1250 & 0.0829 & 0.1239 & 0.0781 & 0.0829 \\ 0.0421 & 0.0322 & 0.0781 & 0.0829 & 0.1250 & 0.0421 & 0.0781 & 0.1239 & 0.0829 \\ 0.0244 & 0.0421 & 0.0421 & 0.0391 & 0.0782 & 0.0391 & 0.0829 & 0.0829 & 0.1167 \end{bmatrix}.$$

As before, the element in the ijth position, multiplied by $\frac{h^2}{D}$, gives the deflection of the plate at point i of the network due to a unit load at point j. The deflection of the plate for any type of loading may be found by use of the superposition principle. For example, the deflection at the center of the

plate due to a uniform load of intensity q is

$$w = \sum_{k=1}^{9} G_{5k} \times qh^2 = 0.0438 \frac{qa^4}{Et^3},$$

where a is the length of one side of the plate,
t is the thickness,
and E is the modulus of elasticity.

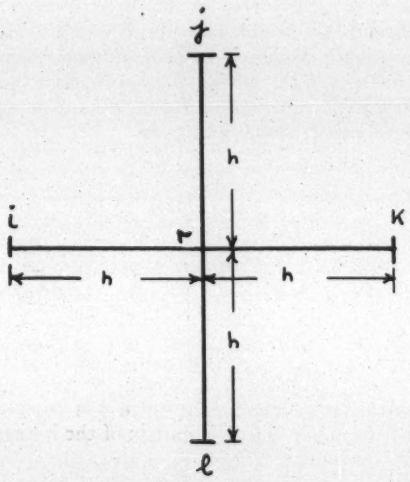

FIG. 3.

This formula has been obtained by replacing the flexural rigidity D by

$$\frac{Et^3}{12(1 - \nu^2)}$$

and ν, Poissons' Ratio set equal to 0.3.

The exact solution for the deflection at the center is [6]

$$w = 0.0443 \frac{qa^4}{Et^3}.$$

It is seen that the value given by our general method with the use of only 9 network points, differs by approximately 1 per cent. from the exact value.

Another case in which the exact solution is known is that of a uniform load applied along the axis of symmetry parallel to a side of the plate. Under such a loading, the deflection at the center is known to be [6]

$$w = 0.0736 \frac{qa^3}{Et^3}.$$

Using our method w is given by

$$w = (G_{35} + G_{55} + G_{75})qh$$
$$= 0.0791 \frac{qa^3}{Et^3}.$$

The difference is about 7.5 per cent.

It is to be noted that the bending moments M_x and M_y, given by [6]

$$M_x = -D\left(\frac{\partial^2 w}{\partial x^2} + \nu \frac{\partial^2 w}{\partial y^2}\right),$$

$$M_y = -D\left(\frac{\partial^2 w}{\partial y^2} + \nu \frac{\partial^2 w}{\partial x^2}\right),$$

can also be readily determined by substitution of the finite difference expressions previously given for the derivatives.

Our general method of procedure has the advantage that it can be applied to many specific problems for which no exact solution is known. Such problems as bodies with non-uniform mass or stiffness, or bodies subject to complicated boundary conditions are amenable to this treatment.

The author wishes to acknowledge the assistance of Messrs. John A. Sauer and Warren Young in the preparation of this paper.

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All-Weather Laboratory for Testing Bomber Instruments.—FRANCIS A. WESTBROOK reports in *Heating and Ventilating*, Vol. 39, No. 9, that rain, snow, fog, any degree of humidity, intense sunlight, and temperatures ranging from − 50° to + 150° F. are some of the weather effects which can be produced at will in a special testing room recently built by the Sperry Gyroscope Company. Many of the company's products such as directional gyros, gyro-horizons, high intensity searchlights, and others, especially those installed on the Army and Navy bombers, must function properly in all climates and temperatures. Under war conditions it is not possible to make tests in all parts of the world to develop this equipment, and, under any circumstances, the work can be done more quickly and satisfactorily in a laboratory where the atmosphere is under control. The room is 10 ft. high by 11 ft. square. It is made of an inner shell of welded stainless steel with insulating material surrounding it. On account of the great changes in temperature the expansion and contraction of the steel is a serious problem, and it has been met by suspending the shell from its top center. Low temperatures are produced by use of a 5-ton Freon unit, with supplementary cooling provided by a dry ice booster unit. The compressor is driven through a Reeves variable speed motor pulley in order to provide for the required temperature ranges. The stainless steel construction makes the room corrosion-proof from the moisture which is bound to condense on the walls, and it is impervious to the ultra-violet rays used to simulate intense tropical sunlight. The men working in this laboratory wear bathing suits or heavy flying suits, depending on the kind of weather they are using. Communication with the outside is by means of a two-way speaking device or signalling through a window having six layers of glass. Much valuable information has already been secured from tests conducted in this laboratory. For instance, some greases harden to the consistency of paving asphalt at low temperatures, and some synthetic rubbers become comparable to bakelite, while certain types of plastics turn brown and break under exposure to ultra-violet light and high temperatures.

R. H. O.

THE THREE-COMPONENT ACCELEROMETER.

BY

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Drexel Institute of Technology,
Philadelphia, Pennsylvania,
June 15, 1942.

There are three distinct fields where the use of an accelerometer is of great value. These fields are:

1. Automobile transportation, including buses and trucks.
2. Railway transportation, including street railways.
3. Airplane transportation.

In each of these fields accelerations are encountered which may be divided into two groups:

1. Accelerations of comparatively low frequency which are largely under control of the operator.
2. Accelerations of higher frequency which result from the vibration of the parts of the moving body, due to structural flexibility of equipment and to the conditions of travel.

The second group of accelerations largely determines the riding qualities of transportation equipment.

The design of an accelerometer for each group of accelerations requires special treatment. For accelerations due to increasing or reducing speed or to airplane maneuvers an accelerometer of low natural frequency is desirable. For accelerations found in transportation equipment which affects riding comfort of passengers an instrument of higher natural frequency is required. An instrument for measuring accelerations for either low or high frequencies should be adequately damped especially when occasional accelerations are encountered whose frequencies are in the resonant range of the instrument. The problem of proper damping of the instrument offers the greater difficulty in the design of an accelerometer for either of these groups of accelerations.

The accelerometer here described has been designed more especially for the higher frequency accelerations and special means have been provided for damping. In the design of any type of accelerometer it is essential that the natural frequency of the element be at least twice as high as the highest frequency of accelerations to be measured, and that sufficient damping be provided. These requirements have been met in the design of the accelerometer here described.

To secure complete information regarding accelerations this accelerometer has been designed to measure components of accelerations in three mutually perpendicular directions simultaneously and to record them upon the same photographic film.

The principle involved in this instrument is the action of accelerating forces on a cantilever pendulum of high natural frequency, which for the instrument here described is about 130 v.p.s. For measuring the three components of acceleration three pendulums are used so disposed that each responds to only one of the three components of acceleration mutually perpendicular to the other two.

Distinctive and important features embodied in this accelerometer are:

1. Large magnification of the motions of the pendulums.
2. Air damping of the pendulums over a wide range.
3. Disposition of the pendulums so that the three components of acceleration may be observed on a ground glass screen at the same time that they are being recorded on a photographic film.

How these features are secured will appear in the description of the instrument.

Fig. 1 shows the construction and operation of an element for one component of the accelerometer, let us say, the vertical. A pendulum strip (*a*) of phosphor bronze is clamped rigidly to a pedestal (*b*) of a rigid base (*c*). The free end is weighted by the masses (*d*) and (*e*) whose mass together with the stiffness of the pendulum strip determines the natural frequency. The mass (*e*) is attached to the hollow diaphragm (*f*) of thin German silver which serves to dampen the motion of the pendulum. Damping is produced by forcing air into

and out of the hollow diaphragm through a needle valve (*g*) during vibration of the pendulum. By adjusting the opening of the valve damping may be varied from a few per cent. to full critical and thus optimum damping may be secured. The motion of the pendulum during acceleration is measured by attaching to the free end a pin (*h*) to which is attached a thin phosphor bronze ribbon (*i*) which extends upward forming a double loop and passes about a spindle (*j*) and from thence to a spiral spring (*k*) attached to a rigid support (*l*). During

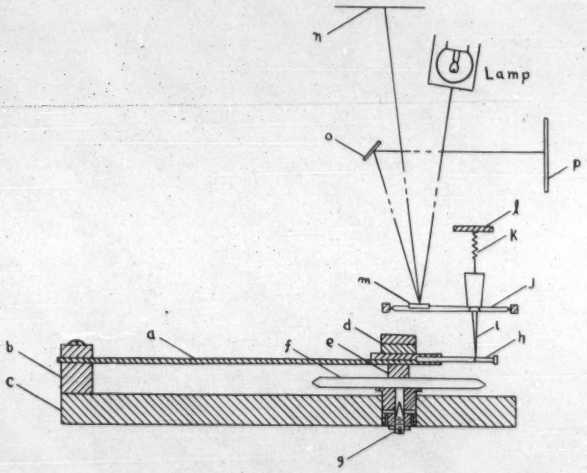

FIG. 1.

the motion of the pendulum the spindle is caused to rotate and a part of a beam of light falling upon the mirror (*m*) is deflected upward and is brought to a focus upon a photographic film (*n*) and the other part upon a plane mirror (*o*) and from thence to a ground glass screen (*p*).

A photograph of the Three Component Accelerometer embodying three of the elements thus described is shown in Fig. 2. The construction and disposition of the parts are shown in Figs. 2(*a*) and 2(*b*). The three pendulums (1), (2),

and (3) of flat strips of phosphor bronze are shown in their relative positions. These pendulums are mounted on supports (4), (5), and (6) which are rigid parts of a cast aluminum base. Pendulum (1) is mounted so that it is free to vibrate in a horizontal direction. Pendulum (2) is mounted so that it may vibrate in a vertical direction. Pendulum (3) is free

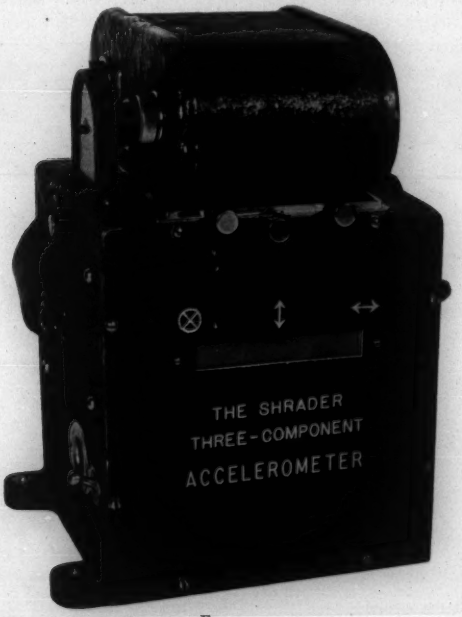

FIG. 2.

to vibrate in a horizontal direction at right angles to that of pendulum (1). The diaphragms (7), (8), and (9), attached to the free ends of the three pendulums and to the heavy base, serve to dampen the motions of the pendulums.

The optical system consists of the concave mirrors (10), (11), and (12). Light beams from the electric lamp (13) falling upon these mirrors are reflected upward and through a

slit to a photographic film which is carried past the slit by a motor driven sprocket (14) in the film holder (15). The beams of light from the mirrors (11) and (12) are reflected directly upward to the slit. Due to the fact the spindle which carries mirror (10) must be mounted vertically, the right angled prism (16) is used to change the direction of the incident and reflected beam so that the light passes through the same slit and upon the same photographic film.

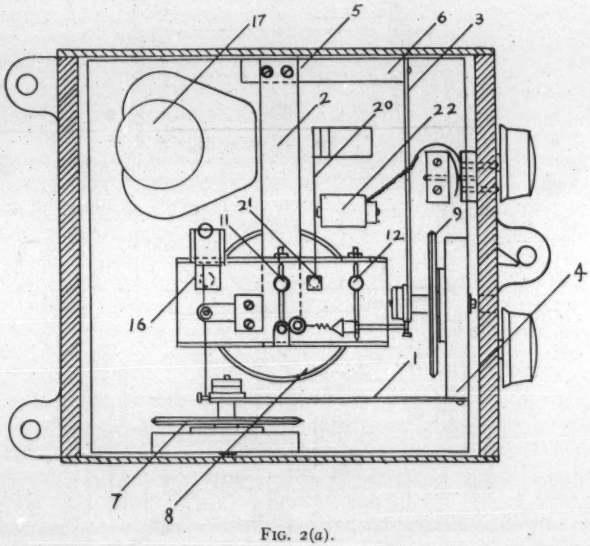

FIG. 2(a).

A small 6-volt shunt motor (17) for driving the photographic film is mounted inside the case and by reduction gears (18) is connected to the sprocket shaft of the film holder. The reduction gears provide for a high and low speed of the film. The high speed is about 2½ inches per second and the low speed is about 2½ inches per minute. Shifting from one speed to the other is accomplished by means of a gear shift knob (19) which protrudes through the case to the outside.

Shifting from one speed to the other may be done almost instantaneously while the motor is running, so that practically no part of a record is lost during the shifting of the gears.

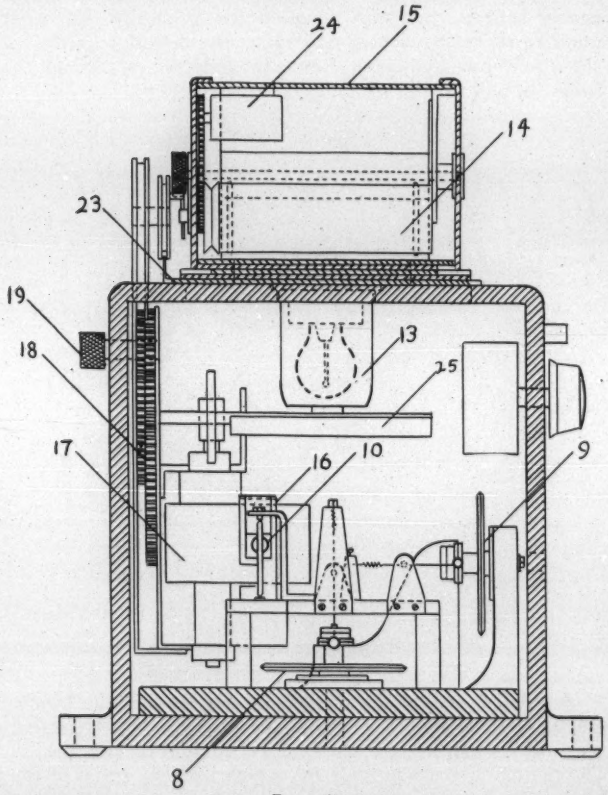

FIG. 2(*b*).

The higher speed of recording is desirable when a record of acceleration is to be made for study under some particular

condition of operation. The lower speed is used when only the magnitude of accelerations is to be recorded over a long period of time. Each of the above speeds may be doubled or quadrupled by changing the single thread worm and gear of the motor to a double or quadruple worm and gear. Provision is made whereby this change is easily accomplished.

Simultaneous visual observations of accelerations may be made on a ground glass scale at the front while a photographic record is being made. For this purpose a lamp (13) having a long straight filament is used so that parts of the beams reflected from the concave mirrors (10), (11), and (12) are intercepted by a plane mirror (25) and reflected to a scale at the front of the instrument while the unintercepted part passes to the photographic film.

For the slow rate of recording less intensity of light is required than for fast recording. To vary the light intensity to suit these conditions a variable resistance and a fixed resistance are placed in series with the lamp. With a certain fixed resistance in the circuit the variable resistance is adjusted to proper intensity for slow recording. For fast recording the fixed resistance of proper value is automatically shorted to increase the intensity of illumination. For either change from slow to fast speed or fast to slow speed the light intensity is changed automatically to the proper value by the operation of shifting of the gears.

A timing record for accelerations at both high and low speeds of recording is very desirable. For fast recording a reed (20) tuned to a frequency of 30 cycles per second is so placed that it intercepts at each vibration a beam of light from a concave mirror (21) so that dots appear on the photographic film at intervals of 1/30th of a second. This reed is set into vibration by automatically energizing a selenoid (22) once for every two revolutions of the film sprocket. In this way an uninterrupted timing record six inches long on the film is obtained.

For slow speed recording the dots for 1/30 second intervals are so close together that they form a continuous line. For this reason a method of timing for slow recording had to be devised. A simple and satisfactory method was devised which made use of a watch with a full sweep second-hand.

The hands were removed and a thin aluminum disk was substituted for the second-hand. This disk was slotted radially at 5 second intervals and a concave mirror was attached to the watch face beneath the radial slits. The watch was then mounted so that light from this mirror passed through the slits during rotation and was brought to a focus on the photographic film. In this way a continuous succession of dots at 5 second intervals was obtained on the film. It is obvious that longer or shorter timing intervals may be made in this manner.

The film holder is an oval shaped box which slides in guides on top of the instrument case to which it is firmly clamped. This holder has a sprocket directly over a slit through which the light from the mirror passes. By means of a clutch (23) the sprocket is connected to the motor and the film on a spool in the film holder is driven past the slit and rerolled upon a second spool. The slit in the film holder is automatically opened when the clutch is connected. When the clutch is disconnected, the slit is automatically closed, thus insuring against the entrance of light into the film holder when not in operation. A revolution counter (24) geared to the film sprocket indicates the number of revolutions of the sprocket. Each revolution of the sprocket exposes three inches of the film. Rollers inside the film holder press the film against the sprocket and prevent the film from becoming disengaged during operation. Great care has been taken to make the film holder light proof.

The film holder will hold about 35 feet of 70 mm. motion picture film. Since this film may be secured in 100 ft. lengths it is economical to use one roll for three loads. By attaching strips of black paper to the ends of the film in the dark room, the spool may be prepared for daylight loading. Care should be taken however to make sure that this paper fits snugly between the flanges of the spool and to avoid unnecessary exposure of the loaded spool to daylight. Ordinarily, the positive film is used since it is sufficiently sensitive for the purpose.

To make a record with the accelerometer the instrument should be fastened securely to the part whose acceleration is to be recorded. Since three components of acceleration are

measured at the same time, it is necessary that the instrument be placed in such a position that the three components measured bear the desired relative direction to the accelerated object. For instance, if the accelerations in an automobile are to be measured it is convenient to place the instrument so that an observer facing forward faces the accelerometer. In this position it has been arranged so that the component marked X measures accelerations in the direction of travel and a deflection to the right indicates a positive or forward acceleration. The Y-component of acceleration is for the vertical direction and a deflection due to this component to the right measures a positive or upward acceleration. The Z-component measures accelerations sidewise and a deflection to the right indicates an acceleration toward the right. When a photographic print is made from the film, positive accelerations thus designated are indicated for all three components by upward deflections on the print.

The sensitivity of the instrument is determined by:

1. The length and stiffness of the pendulum strips.
2. The weight of the attached masses at the ends of the pendulum.
3. The diameter of the spindles and the optical distance from the mirrors to the film.

For the purpose of testing automobiles and railway coaches for riding comfort the natural frequency should be rather high, say between 75 and 150 v.p.s. The sensitivity of the model which has been made for this purpose is about 1.63 cm. deflection for one "g."

The accelerometer has been calibrated by three different methods:

1. STATIC DEFLECTION DUE TO GRAVITY.

The instrument was placed with the plane of any particular pendulum in a vertical direction. In this position the accelerating force due to gravity does not deflect the pendulum, and the position of the beam of light indicates zero acceleration. The instrument was then turned so that the plane of the strip was in a horizontal direction and the deflection indicated 1 "g." If the instrument was then turned upside down from this position, the difference between this

reading and that of the former reading was 2 "g." In this manner three calibration points for each component were obtained, 0 "g," +1 "g" and −1 "g."

2. STATIC DEFLECTION DUE TO RADIAL ACCELERATION.

By the second method the instrument was calibrated by subjecting the pendulum to central acceleration. To do this a rotating platform was made by mounting an oak board 1½ inches thick, 8 inches wide, and about 4 feet long and balancing it on a turntable which was driven by reduction gears by a ¼ H.P. motor. By measuring the speed of the motor with a tachometer and by determining the ratio of reduction, the

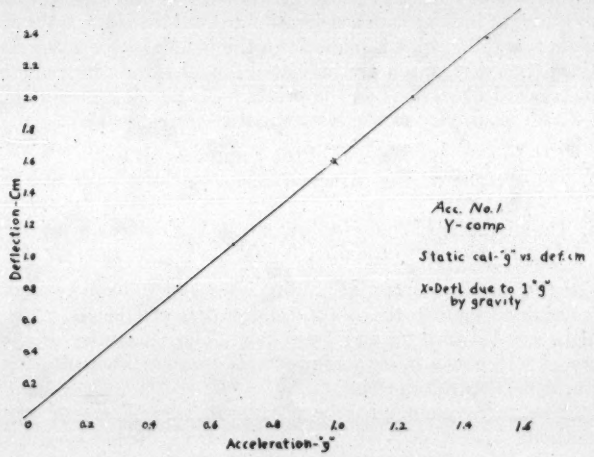

FIG. 3.

rate of rotation of the platform was found. The accelerometer was placed on one end of the board and counterbalanced with the pendulum of the accelerometer at a known distance from the axis of rotation. By varying the speed of the motor, records of steady deflections of the accelerometer at known speeds were made. In this way deflections of the accelerometer were obtained for a range of calculated central

accelerations. The calibration curve for the *Y*-component obtained by this method is shown in Fig. 3. By adjusting the weight of the masses at the ends of the other two pendulums the sensitivities of the other two components were made the same and a common calibration curve was obtained.

The accuracy of this method of calibration is limited by the lack of constancy of the speed of the motor and by the vibration of the turntable. Due to this latter cause the accelerometer record was of variable width instead of a narrow straight line, so that deflections could not be accurately measured. There was also the possibility of inaccuracy of the tachometer. However, the point for 1 "g" indicated on the curve obtained by the first method falls fairly well on the calibration curve shown in Fig. 3.

3. DYNAMIC CALIBRATION.

The third method was a dynamic calibration of the accelerometer. By this method a steel plate $\frac{3}{8}$ inch thick, 6 inches wide, and 5 feet long was mounted firmly on a heavy iron table resting on a cement floor. One end of the plate was clamped to the table by heavy steel cleats leaving the other end free to vibrate in a vertical direction. The accelerometer was attached firmly at the free end of the plate in an upright position with the pendulum for the *Y*-component free to vibrate in the vertical direction. The plate was pulled down and released and then allowed to vibrate with the natural frequency of the loaded plate. To measure frequency and amplitude of vibration of the plate a stylus was attached to the plate at a point corresponding to the location of the element of the accelerometer and this made a record on waxed paper on a drum driven at constant speed by a small synchronous motor.

To make a record the plate was pulled down a desired distance, the recording mechanisms of the stylus and of the accelerometer were started and then the plate was released. The recording was continued until the amplitude of vibration of the plate died down to a small value. By determining the frequency and the decreasing amplitudes of vibration of the plate, a range of accelerations could be calculated. From these values of accelerations and the corresponding deflec-

(a) (b) (c)

FIG. 4. (a) Record of acceleration of vibrating steel plate at 3.05 v.p.s. (b) Record of acceleration of vibrating steel plate at 5.40 v.p.s. (c) Record of acceleration of vibrating steel plate at 8.75 v.p.s.

tions on the accelerometer record a dynamic calibration was made at the known frequency.

The test was made for three different frequencies for three different lengths of the vibrating plate. Parts of acceler-

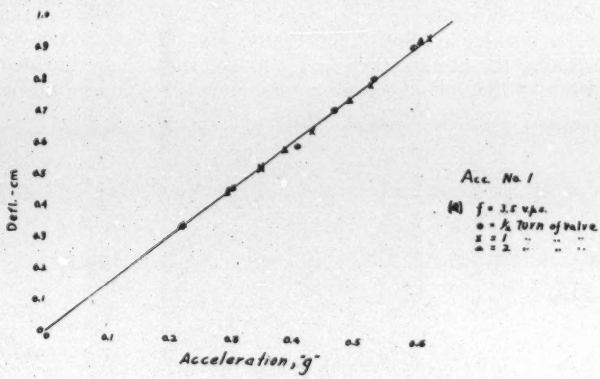

FIG. 5.

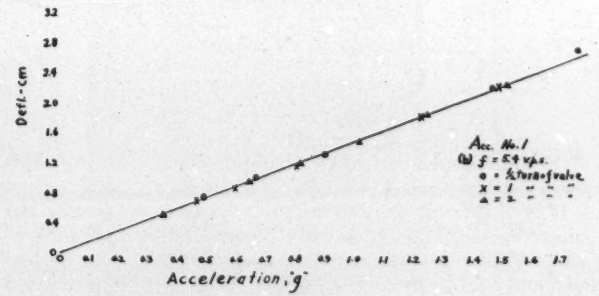

FIG. 6.

ometer records for the three frequencies are shown in Fig. 4, (*a*), (*b*), and (*c*). The calibration curves for these frequencies are shown in Figs. 5, 6, and 7. These curves show a straight line relationship between deflection of the accelerometer and

the calculated values of accelerations. The curves also show that the recorded accelerations are independent of frequency from 3.5 to 8.75 v.p.s.

The effect of damping of the accelerometer was also determined at these frequencies. The amount of damping was varied arbitrarily by varying the number of turns of the valve opening in the damping diaphragm. This was done by opening the needle valve $\frac{1}{2}$, 1 and 2 turns of the threaded screw of the valve. These curves show that the calibration

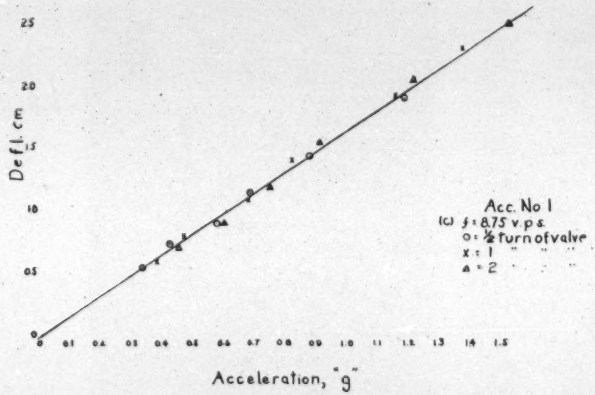

FIG. 7.

curves are independent of the amount of damping over this range.

It is of interest to note that the manner of releasing the deflected plate quite appreciably affected its manner of vibration. When the first tests were made the plate was pushed down and held by a metallic catch. When suddenly released the plate vibrated in a complex manner showing that overtones were present at the initial stage of vibration. These overtones gradually died out leaving a simple wave form which was the fundamental. Later the plate was pushed down and released by hand. Under these conditions overtones were practically suppressed at release and a simple wave was ob-

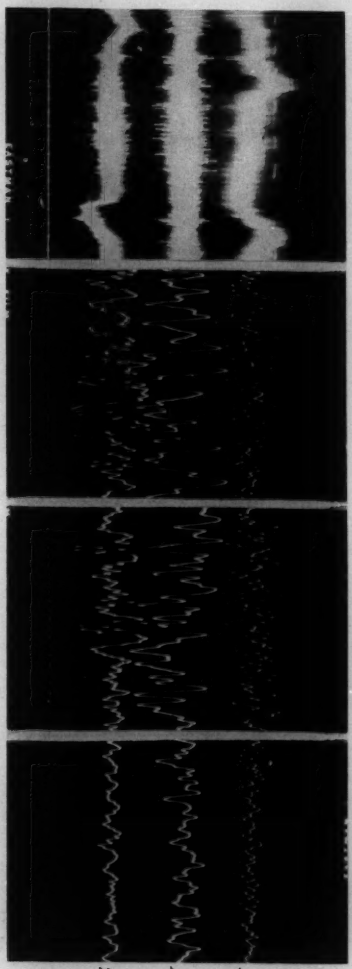

FIG. 8. Record of acceleration in an automobile at 30 m.p.h. X = Back and forth, Y = Vertical, Z = Sidewise. (*a*) On concrete street: Time interval = 1/30 sec. (*b*) At rough street railway crossing. (*c*) On rough macadam street. (*d*) On macadam street: Time interval = 5 sec.

tained. It was also noted that the overtones were stronger for the longer lengths of the vibrating plate. Especial care was taken to avoid complex wave forms which were due to other forms of vibration than the fundamental.

MEASUREMENT OF ACCELERATIONS IN AUTOMOBILES.

To measure accelerations in an automobile the accelerometer was placed on the floor of the automobile to one side near the frame so as to exclude as far as possible the vibration of the floor. Records were made at fast and slow speeds of recording while driving the automobile over selected parts of a roadway. The records so obtained and the conditions under which they were made are shown in Fig. 8(*a*), (*b*), (*c*), and (*d*).

Since no criteria for determining riding comfort have so far been established, it must be understood that records of acceleration to show riding comfort must be purely comparative. It can be safely assumed however that a record showing smaller accelerations and a lower frequency of accelerations would indicate greater riding comfort. This is corroborated by physical experience.

There are many factors which would affect the accelerations found in an automobile, such as the part of the car tested, the make of the car, the condition of the tires, rate of driving, and condition of the roadway. All these things must be taken into account in determining the riding comfort of an automobile.

As a matter of interest a record was made in a standard make of automobile over the new Pennsylvania Turnpike traveling at a normal speed of 60 to 70 m.p.h. Fig. 9 is a part of the record on the Pennsylvania Turnpike.

In this paper is described a special form of accelerometer which uses air as a means of damping. This damping is accomplished by means of thin hollow diaphragms into and out of which air passes through a needle valve during the action of a cantilever pendulum. By the adjustment of the valve damping may be secured from a few per cent. critical up to full critical. By proper adjustment a desired per cent. of critical damping may be secured.

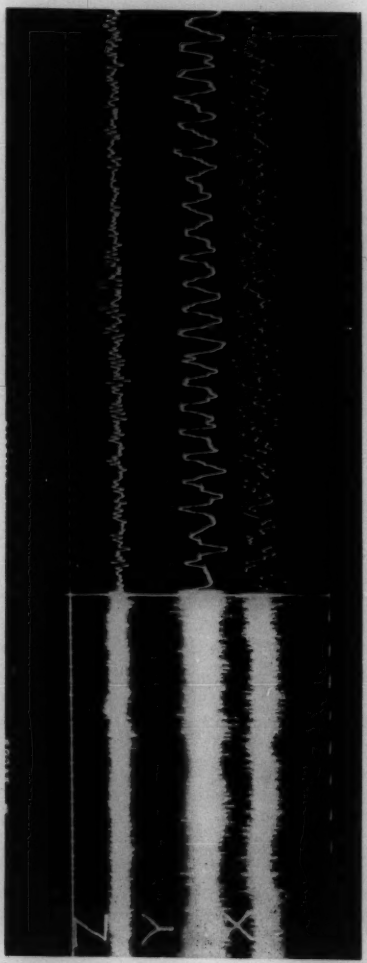

FIG. 9. Record of acceleration in an automobile on the Pennsylvania Turnpike at 60 to 70 m.p.h. Time interval, first part—5 sec., last part—1/30 sec. X = Back and forth, Y = Vertical, Z = Sidewise.

In the design of accelerometer here described the natural frequency is approximately 130 v.p.s. By certain alterations frequencies two or three times lower or higher may be secured. The natural frequency of 130 v.p.s. makes the instrument especially useful in testing transportation equipment for riding qualities.

Large sensitivity at the higher frequencies is secured by large magnification by optical means. Three elements are used so disposed as to measure the three components of acceleration simultaneously and to record them on a photographic film.

Timing records are made both for high and low rates of recording, the time intervals being 1/30 and 5 seconds. The source of power is a 6 volt storage battery. The size of the instrument is about $5'' \times 6''$ and $6\frac{1}{2}''$ high and weighs 13 pounds.

A NEW TYPE OF CONTACT HALFTONE SCREEN.*

BY

J. A. C. YULE, F. B. JOHNSTON, AND A. MURRAY.

In making a photomechanical reproduction of a picture by photoengraving or lithography, the printing press is incapable of applying layers of ink of different strength in the various regions of the picture. A given spot on the paper is either inked or not inked, and there is no gradation between the limits of black and white. The appearance of such a gradation must be introduced by dividing up the inked area into microscopic dots whose size varies in accordance with the density required.

If a pattern of dots with graded edges is printed onto a very high contrast emulsion with varying exposure, a weak exposure will produce small dots, which will increase in size with increasing exposure. In halftone work, the variations of density of the original provide the variations in exposure, while the function of the halftone screen is to give the graded dot pattern. Thus, the halftone screen converts the variable-density image into a variable-size dot image.

Conventional halftone screens have clear openings with sharp edges; hence, in order to produce the required graded-edge dot pattern, they must be held at a distance from the emulsion. The idea of replacing this, with its complications of mechanism and operation, by a vignetted dot screen in contact with the sensitive emulsion is an attractive one. Ever since its suggestion in 1855 by A. J. Berchtold,[1] attempts have been made to utilize it. However, contact screens have never been very widely used because of a number of disadvantages. These have been analyzed in papers by F. J. Tritton and E. T. Wilson,[2] but the pros and cons of the contact screen will be briefly reviewed here.

The main disadvantages of the crossline screen are:

1. High cost of screen and mechanism for operation.
2. Skill and training required to obtain good results.

* Communication No. *880* from the Kodak Research Laboratories.

3. Imperfect tone reproduction in the finished halftone, requiring hand correction, especially in the highlights.

4. Loss of sharpness of detail due to diffraction with the finer screen rulings.

On the other hand, the contact screen, as it has been known up to now, has an even more formidable array of objections:

1. Too little control of contrast.

2. Extreme sensitivity to the presence of dust specks between screen and film.

3. Poor tone reproduction.

4. No improvement in sharpness over the crossline screen, in spite of the elimination of diffraction effects.

5. Short life of screens due to ease of scratching.

6. Formation of Newton's rings in the layer of air between the screen and the film.

CONTRAST CONTROL OF SCREEN.

In spite of all this it seemed that if contrast control could be introduced in some way, the contact screen would have certain uses. A simple solution of this problem was found in the use of screens in which the dot images were colored. The availability of color developers afforded a source of dye images of the proper quality.

When using a crossline screen, contrast is controlled by changing the screen distance or the lens aperture. This varies the contrast of the dot pattern formed by the screen, which, in turn, varies the contrast of the halftone negative or positive. With a contact screen in which the elements are colored, an analogous effect may be produced by means of color filters. The action of this method of contrast control is represented diagrammatically in Fig. 1.

Suppose we wish to make a screen negative from a black-and-white print, using a magenta contact screen, with blue and green filters for contrast control. For purposes of illustration, a step wedge will be used for the original print, its densities being represented at *A*, Fig. 1.

Blue or green light is reflected from the original and passes through the magenta contact screen. The screen dots have a low density in blue light and a high density in green light (Fig. 1, *B*). The sum of the densities of original and screen

is shown at *C*, and the resulting light intensity reaching the film in Fig. 1, *D*. After a suitable exposure time, the film is developed to give a halftone negative with densities shown in Fig. 1, *E*. This is printed onto a copper plate, and after etching, the result shown in Fig. 1, *F* is obtained. The proof is shown at *G*. The blue light, in which the screen dots have low density and contrast, is seen to give much higher contrast in the proof than the green light exposure.

For practical purposes, an orthochromatic film may be used, with magenta and yellow instead of blue and green filters.

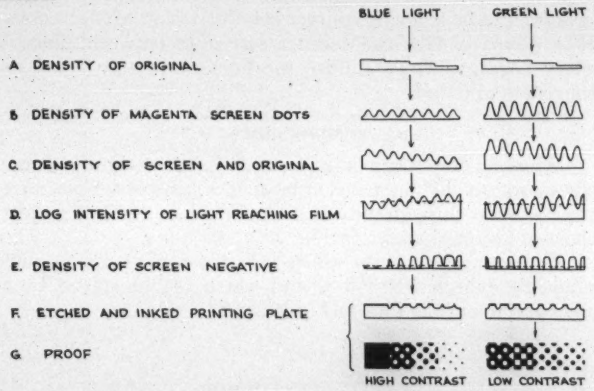
BLUE LIGHT
GREEN LIGHT
A DENSITY OF ORIGINAL
B DENSITY OF MAGENTA SCREEN DOTS
C DENSITY OF SCREEN AND ORIGINAL
D LOG INTENSITY OF LIGHT REACHING FILM
E. DENSITY OF SCREEN NEGATIVE
F. ETCHED AND INKED PRINTING PLATE
G PROOF
HIGH CONTRAST
LOW CONTRAST

FIG. 1. Contrast control by colored contact screen.

There is one disadvantage of the method of contrast control described above. The sharpness of the dots in the screen negative depends on the color of the filter. With a blue filter, the screen dots have a low contrast, and the dots in the negative are not so sharp as with a green filter. The conventional crossline screen suffers from the same disadvantage; i.e., when used with a flat copy, a large lens aperture or a large screen distance must be used, and the dots are not sharp.

CONTRAST CONTROL OF CONTINUOUS-TONE NEGATIVE.

When the screen negative or positive is not made directly from the original, there is a simple way of overcoming this

difficulty. For instance, in deep-etch offset, a screen positive is required which may be produced from a continuous-tone negative. This continuous-tone negative may be colored, and the contrast control may be obtained by varying the contrast of the negative with color filters instead of the screen. For instance, an orange-red screen, whose dots have equal contrast in blue and green light, may be used with a magenta negative. The sharpness of the dots is independent of the filter used, but the contrast of the negative is altered at will to match that of the screens by means of the filters. The use of a dye negative is particularly convenient when the screen positive can be made by contact printing from the continuous-tone negative with the contact screen in between, since a silver negative would diffuse the light and cause a loss of sharpness of detail.

EXPOSURE CHART.

Whether the contrast is controlled by using a colored screen or a colored negative, or both, it is possible to determine the exposures through the two filters by means of an alignment chart of the type shown in Fig. 2.

Theoretical equations which the contact-screen exposures would be expected to follow and which can be solved by a nomograph such as that in Fig. 2 are:

$$axT_s^n + byT_s^m = c$$

and

$$axT_h^n + byT_h^m = d,$$

where x and y are the rose and yellow filter exposure times; a and b are constants depending on the sensitivity of the film to the rose and yellow light employed; T_s and T_h are the shadow and highlight transmissions of the negative measured through the filter used in the densitometer; n and m are constants, depending on the spectrophotometric curve of the negative and the filters used; and c and d are constants determined by the distribution of density in the screen dot and the size of shadow and highlight dots desired.

The experimentally determined exposure chart does not coincide exactly with the theoretical curves, probably owing to the reciprocity failure of the film.

To determine the exposure required for making the screen positive, the highlight and shadow densities of the negatives

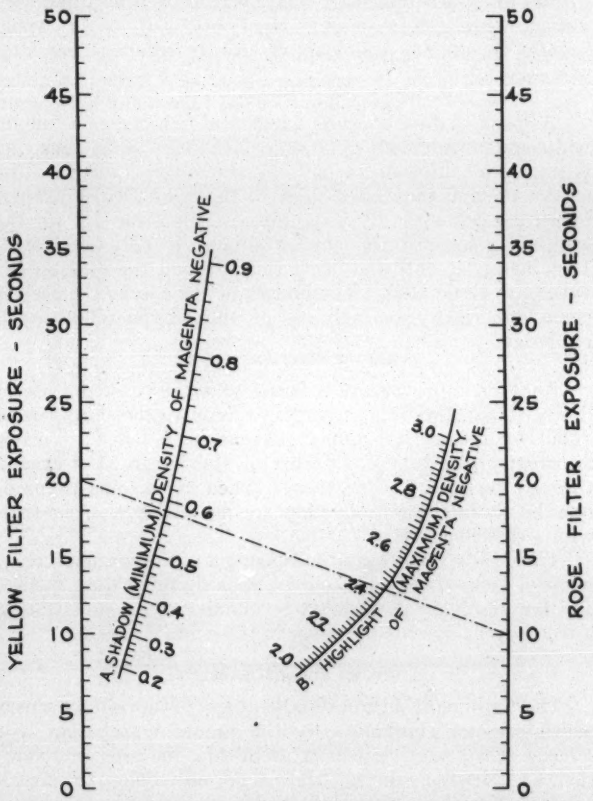

FIG. 2. Contact-screen exposure chart, for use with contact screen at six feet from the printing lamp (500 watts), using film developed for two minutes at 65° F.

are read through a complementary filter. A straight edge joining the points corresponding to these densities on Curves

A and *B*, Fig. 2, will cut the exposure scales at points giving the correct exposure. For instance, under the particular conditions for which this chart was constructed, a negative with a shadow density of 0.58 and a highlight density of 2.45 would require 20 seconds yellow filter and 10 seconds rose filter exposure.

DUST SPECKS.

A speck of dust between screen and film causes a minute white spot surrounded by a large dark ring. This dark ring is caused by diffusion of light by the silver grains into the shadow behind the dark centers of those dots which are not in perfect contact. By using an optically clear dye for the screen in place of a silver image, this is virtually eliminated. It is, however, only the black rings around the dust specks which are eliminated. The images of the specks themselves come out clearly on account of the sharpness of detail rendering.

HALFTONE RESOLVING POWER.

Another improvement is found to accompany the use of dye screens. Previous attempts to improve the sharpness of detail by the use of contact screens have failed. This is apparently due to the diffusion of the image as it passed through the silver in the screen. When dye screens are used, fine details in the reproduction are noticeably sharper than with a crossline screen.

Thus, three important disadvantages of the contact screen, namely, lack of contrast control, sensitivity to dust specks, and low resolving power, can be eliminated by substituting a transparent dye for the silver in the contact screen.

NEWTON'S RINGS ELIMINATED.

There still remain three disadvantages of the contact screen which are not eliminated by the use of transparent dye screens—their relatively short useful life, the tone reproduction, and Newton's rings. Methods of protecting the screens or renovating them when scratched have not yet been investigated. It has been found, however, that Newton's rings can be completely eliminated by special preparation of the emulsion of the screen and of both surfaces of the negative during manufacture of the film.

TONE REPRODUCTION.

There remains a most important phase of the investigation—that of tone reproduction.[3]

Tritton [2] discussed tone reproduction with halftone screens in some detail, reaching the conclusions that the ideal contact screen had never been made, and that we could not say what the ideal screen would be like because of the numerous vari-

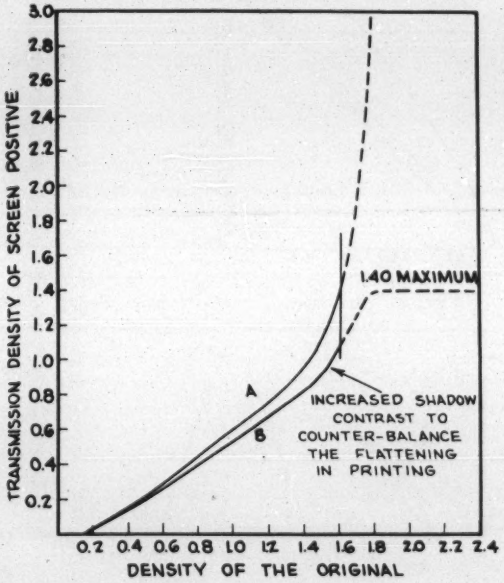

FIG. 3. Tone rendering of screen positive made with the contact screen: Curve A. Actual transmission densities of screen positive. Curve B. Densities of screen positive corrected to maximum of 1.4.

ables in the printing process. While this is academically true, it has been found, by comparing screen positives and press sheets produced by a number of lithographers, that the variation among the results obtained by different companies is not so great as anticipated. By making a screen which will give

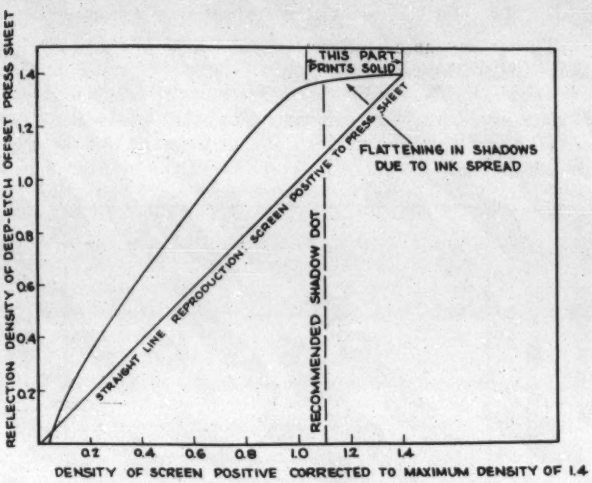

FIG. 4. Tone rendering of deep-etch offset printing.

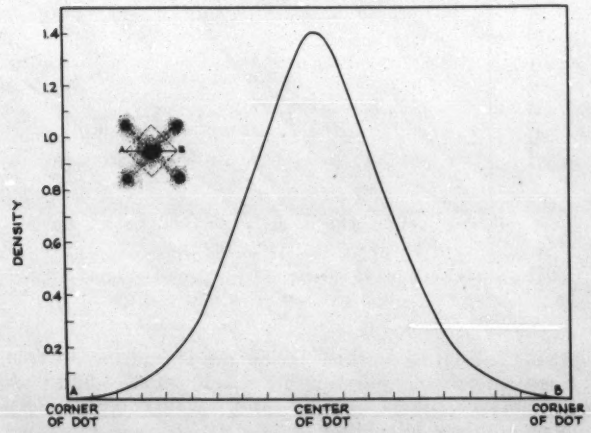

FIG. 5. Cross section of ideal contact-screen dot for ink density of 1.40, not corrected for distortions of tone rendering introduced in the printing process.

correct tone reproduction under average conditions, most lithographers will obtain good results.

The chief difference between the density of the screen positive and that of the printed reproduction is due to the difference in density of the black dots. The individual dot density in a screen positive is likely to be above 3.0, while a

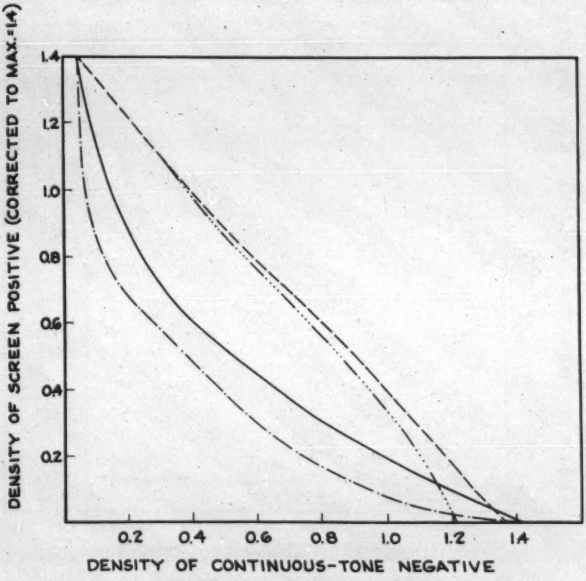

FIG. 6. Tone rendering obtained with "positive" screens, made with different apertures.

printing ink rarely has a density above 1.4. This makes an important difference in the shape of the reproduction curve,[4] as shown in Fig. 3. For this reason, screen positive densities given in Figs. 6 to 9 have been corrected to a maximum density of 1.4.

When this correction is made, deep-etch lithographic proofs can be produced whose densities agree well with the corrected

densities of the screen positive. However, in commercial practice, with deep-etch offset, ink spreading causes a general increase in contrast, especially in the highlights, and a flattening of the deepest shadows (Fig. 4).

The density distribution in the cross section of a dot in a screen designed to give perfect tone reproduction,[5] using a continuous-tone negative of density range 1·4, is given in

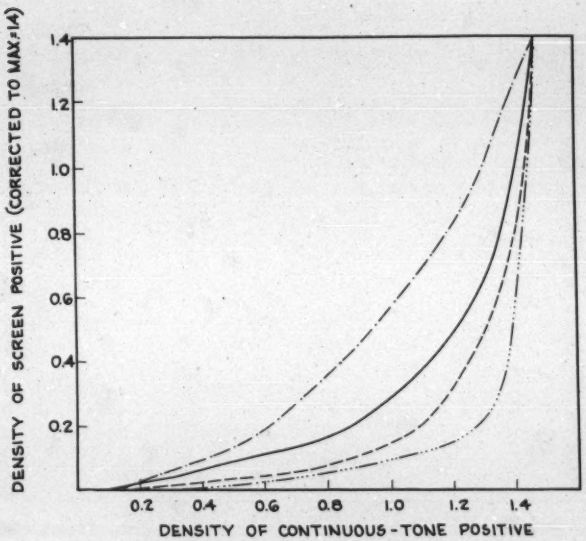

FIG. 7. Tone rendering obtained with "negative" screens, made with different apertures.

Fig. 5. This differs from previously published curves[3] in that it is corrected for the maximum density of the ink. However, no correction for other distortions occurring in the printing process has been applied.

Assuming that the various steps in the reproduction process are carried out in a fixed manner, the main method of controlling the tone rendering given by a contact screen is by

means of the density gradient in the screen dot, which can be controlled in making the screen. The density gradient in the dot depends on the light distribution reaching the emulsion (controlled by aperture, camera extension, and screen pitch) and on the response of the film to this light distribution (depending on the length of exposure, the characteristic curve of the film, and resolving power). It is beyond the scope of

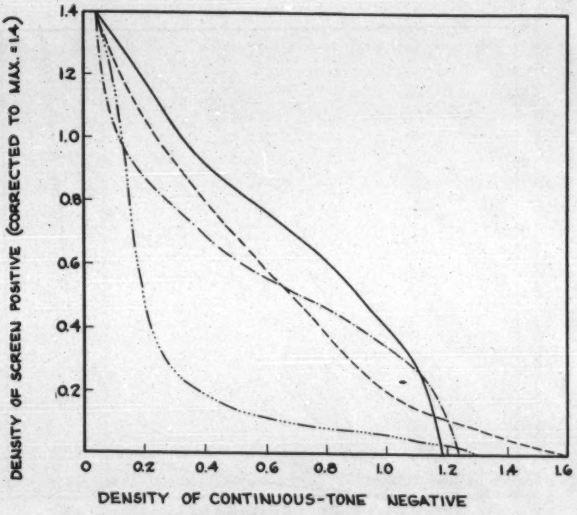

FIG. 8. Tone rendering obtained with "positive" screens, made with varying emulsion response.

this paper to describe in detail the relationship of the reproduction curve to the method of making the screen; however, some of the reproduction curves we have obtained are given in Figs. 6 to 9, and illustrate the remarkable control of tone reproduction which is possible. Figures 6 and 7 show some of the changes which result from changing the aperture, while the curves in Figs. 8 and 9 are from screens made with the same aperture but exposed and processed in such a way that

the emulsion response was different. The curves of Figs. 6 and 8 were obtained by using the screens as "positive" screens (i.e., screens for use with a continuous-tone negative), and Figs. 7 and 9 by using them as "negative" screens. In making these screens, a single aperture with graded density was used instead of making several exposures with apertures of different sizes.

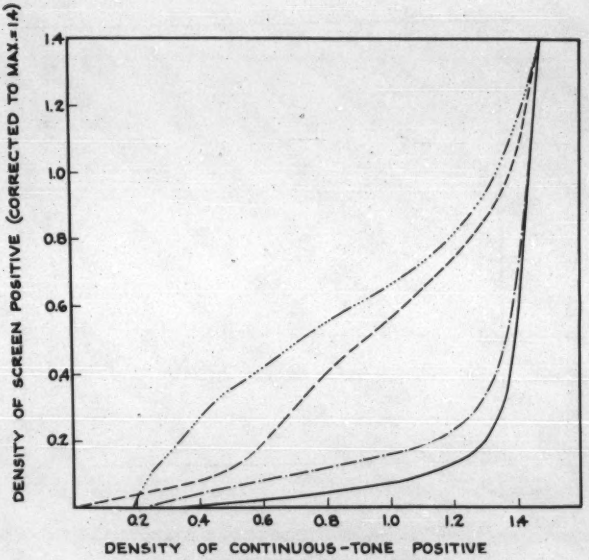

FIG. 9. Tone rendering obtained with "negative" screens, made with varying emulsion response.

It is easily shown that if a screen negative is made in a camera with a certain aperture or combination of apertures, the tone reproduction in a positive made from it may be expected to be the same as if a contact screen, developed to a gamma of unity, had been made under the same conditions as the screen negative, and a screen positive made through it. This will, of course, only be true if the contact screen image all

lies on the straight-line portion of the characteristic curve. Therefore, it would be surprising if the tone reproduction obtained with a normally exposed contact screen were any better than that obtainable with a crossline screen. On the other hand, in spite of the extraordinary range of apertures [6] which have been tried out for making screen negatives and

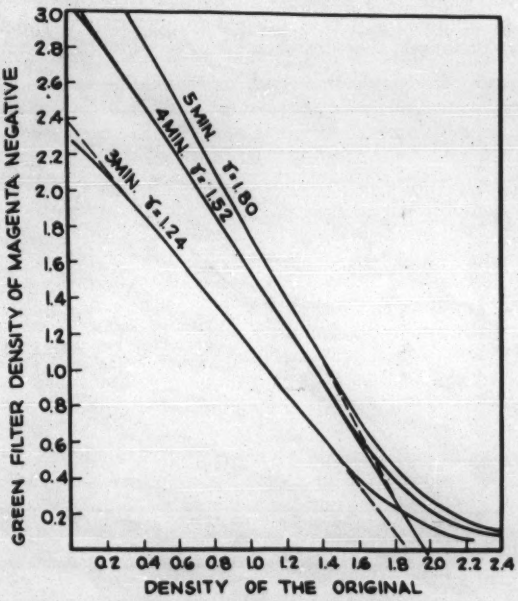

FIG. 10. Characteristic curves for magenta developed commercial screen film. Continuous agitation at 65° F.

positives, the optimum conditions have rarely been realized in commercial production, since it has been the exception rather than the rule to plot tone reproduction curves. It is often felt that every possibility has been tested, but the possibilities of control along this line are much greater than is commonly realized, although some of them are rather

difficult to use except under carefully controlled conditions. Some of these methods will be dealt with in a later paper.

Moreover, in making contact screens, it is not necessary to use the straight-line portion of the characteristic curve. This factor, in conjunction with the manipulation of apertures and screen distances, opens up unusual possibilities of control. In fact, almost any desired form of tone reproduction curve can be obtained. It is of interest to note that working out screen distances, aperture sizes, etc., according to geometrical

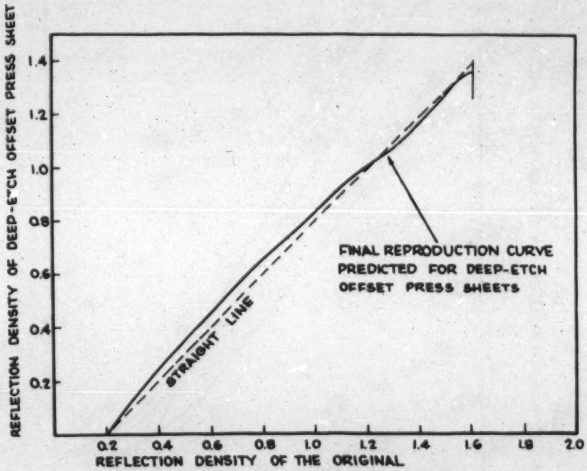

FIG. 11. Tone rendering of a contact screen process now available commercially.

optics (penumbra theory) alone has proved quite inadequate.[7] It has been found necessary first to choose a screen distance which gives a favorable diffraction pattern, and then to work out a suitable aperture for the purpose in view.

Although it may be said that the tone reproduction is built into the screen, instead of depending on the skill of the operator, this is not strictly true. It depends to a slight extent on the film and developer which are used in making the screen positive. This is due to edge effects (Mackie line,

Eberhard effect, image-spreading effects, etc.) which occur during development and are particularly marked with formaldehyde developers such as are used for making halftone screen film negatives.

There is one disadvantage of correct tone rendering which has been described by Tritton, namely, the decrease in highlight dot sharpness which accompanies improvement in highlight contrast. However, by using extremely high contrast films, sharp dots can be obtained even in the highlights. This problem is inherent in correct tone rendering, and the same effect is found in screen negatives made from ordinary crossline screens, provided they are used in such a way as to give correct tone rendering.

Since highlighted effects are required for lithography, there is more room for improvement in tone reproduction than in photoengraving. Moreover, a very peculiar dot gradation is required for photoengraving screens in order to compensate for the effect of etching. A commercial process has been worked out for photolithography which is outlined below. Magenta contact screens for making halftone negatives may have practical uses as well.

1. A magenta continuous-tone negative is made from the original by direct development. Characteristic curves are shown in Fig. 10.

2. A screen positive is made by contact from this through an orange-red screen in a vacuum printing frame, with the screen sandwiched between the negative and the film. A 500-watt projection bulb is used at a distance of 4 feet or more in a special printing lamp with magenta and yellow filters. Contrast is controlled by varying the length of the magenta and yellow filter exposures. The former alone gives a low contrast, the latter a high contrast, and intermediate contrast may be obtained by giving part of the exposure through each of the two filters.

3. The screen positive is printed onto a zinc or aluminum plate, using the deep-etch process.

The form of the tone reproduction curve to be expected under average conditions of printing is shown in Fig. 11. It will be seen that it very closely approximates a straight line.

In conclusion, it may be said that while all the disadvantages of the contact screen, except that of short life, appear to have been eliminated, time alone will show whether the new type of contact screen will stand up to the severe test of practical conditions. We feel, however, that with the introduction of contrast control, higher resolving power, and improved tone reproduction, the contact screen will at least have an opportunity to show what it can do.

SUMMARY.

The development of an improved type of contact screen is described. By using a transparent dye for the screen image, and also in some cases for a continuous-tone negative for use with the screen, contrast control is obtained with color filters, and increased resolution of detail results. Improved tone reproduction is incorporated in the gradation of the screen dots. The greatest improvement in quality is obtained in deep-etch offset printing, where it is convenient to make a highlight screen positive from a magenta negative by contact through an orange-red contact screen.

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ROCHESTER, NEW YORK,
August 13, 1942.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

THE BUILDING AS A DEFENSE AGAINST FIRES FROM BOMBS.

The structures used as living quarters or business establishments cover a wide range, from liability to asset, so far as the fire hazard from bombing is concerned. Incendiary or combined incendiary and explosive bombing from airplanes constitutes the most advanced and effective use of fire as a weapon in warfare. The hazard is not only to the individual building, its occupants and contents, but also to the community as a whole. By the setting of a big fire or many fires, a conflagration may be created, uncontrolled and uncontrollable, except for the dearth of material to burn.

The degree of hazard to municipalities depends to a large extent on the prevailing type of building construction within a district, spacing of buildings, and their occupancy or contents. It is gauged by the amount and kind of combustibles in the building and its contents, how these are contained, confined or segregated, the effect of fire therein on the integrity of the building construction, and the extent to which the latter serves to prevent origin and subsequent spread of fire within, and communication of fire to neighboring structures.

The most effective incendiary bombing from airplanes has been with relatively small bombs weighing only a few pounds, of which a thousand or more constitute a plane load. These are made to have low penetrating power so they will not go entirely through buildings but come to rest at some point within them. Roofs that withstand without perforation the impact of such bombs are an effective safeguard against them. The resistance of existing roofs can be increased for the purpose, or a layer of incombustible material can be placed on an attic or upper floor to stop the bomb, some of the impact energy of which has been lost in going through the roof construction. Against attacks with the larger incendiary bombs

* Communicated by the Director.

and combined attacks with demolition or high-explosive bombs and fire bombs, it may not be practical or possible to provide such structural protection.

After a fire bomb enters a building, the sequence of events is about the same as for the more common fire origins. If the building is of incombustible construction with only minor amounts of combustible contents, the consequences may not be serious so far as building and contents are concerned, since the fire is not likely to spread rapidly and it can be controlled in its initial stage. For greater amounts of combustible contents, the effect of the type of building construction is less significant, but segregation by means of closely spaced fire walls or barriers is of decided assistance in preventing the fire from getting beyond control.

The type of building construction has a very great influence in preventing communication of fire from building to building and the creation of conflagration conditions. After disastrous fires over a period of several hundred years in cities of Western Europe, buildings within given distances from others were required to have masonry exterior, or exterior and interior bearing walls. This has been found to be effective in preventing sweeping fires where buildings are of moderate size with no large amounts of combustible contents. However, the Baltimore conflagration of 1904 swept through some fifty city blocks of three to five story buildings of this type, housing largely commercial occupancies. The conflagration was stopped on one side by modern fire resistive buildings which, while damaged or partly burned out, did not communicate fire to the structures beyond them.

There have been incidents in recent warfare to indicate the superiority of incombustible fire resistive construction in preventing excessive fire damage from bombing. Thus, Madrid, besieged with an attacking force in its outskirts for over a year, suffered comparatively little from fire, while important parts of Warsaw built up with masonry-walled buildings having interior wood framing were destroyed with incendiaries dropped from airplanes. The attack on the "Old City" portion of London gave similar evidence and on other occasions general conflagrations were apparently prevented by only narrow margins. Again Malta, the most bombed

city on the face of the earth, has been able to survive because bombardments, while causing buildings to collapse, have not started fires of any consequence. This is probably because the buildings have masonry interior as well as exterior walls—a type of construction which has been the general urban building practice in Southern Europe for the past few hundred years.

While it may not be possible, under present conditions in the United States, to effect structural changes that will directly decrease the community hazard, that to individual buildings can be reduced with roof and opening protections and subdivision of areas. By the same token, any measure that prevents or restricts fires in individual buildings serves also in a measure as community protection. In any case, the general protective measures should be planned with respect to the hazard presented by the particular structural conditions prevailing in a given community.

A paper on this subject was presented by S. H. Ingberg, chief of the Bureau's fire resistance section, at the 27th annual meeting of the Building Officials' Conference of America and will be published in the proceedings of that organization.

FRESNEL REFLECTION OF DIFFUSELY INCIDENT LIGHT.

The reflection factor of a plane boundary between two media has been computed by Deane B. Judd, using the Fresnel formula for unpolarized, perfectly diffused incident light as a function of the relative index of refraction of the media. As explained in the *Journal of Research* for November (RP1504), because of total internal reflection, the factors depend upon whether the diffuse flux is incident externally or internally. For example, diffuse light in air incident on the plane surface of glass of index 1.5 is 9.2 per cent. reflected; but if the perfectly diffuse light is incident internally, the reflection factor is 60 per cent.

AN IMPROVED VOLUMENOMETER.

A volumenometer has been used at the Bureau for the past six years to measure the solid volumes of specimens

varying in size up to that of standard building bricks. In order to test the larger standard refractory bricks, a new instrument was built by J. C. Richmond, John B. Peterson, and Winslow H. Herschel in 1941. Certain changes in design were incorporated to facilitate the operation and improve the accuracy.

The chief feature of the new design is the use of a closed-cistern altitude-type mercurial barometer to measure pressures, replacing the simple manometer previously used. A vernier index permits readings to 0.1 mm. of mercury.

The barometer was designed for use in a constant-temperature room (21.1° C.) where the acceleration of gravity is 980.1 cm./sec^2. Under these conditions, it will indicate pressures directly, and the indicated pressure, without correction, will have a maximum deviation of 0.2 mm. of mercury from the actual pressure, corrected to 0° C. and gravity at sea level. A barometer of this type can be designed to correct for any given conditions of temperature and gravity, or a calibration chart can be prepared for use at temperatures other than the standard.

The use of this barometer to measure pressures in the closed system eliminates inaccuracies arising from changes in atmospheric pressure during a test, and operation of the instrument in a constant-temperature room eliminates inaccuracies due to changes in temperature. The instrument is designed as a self-contained unit, and may be easily moved from place to place.

CATALYZED HYDROLYSIS OF PROTEINS.

Proteins are customarily broken down into their constituent simpler components, the amino acids, by boiling in concentrated solutions of strong acids for periods of several hours. This drastic treatment usually results in the partial destruction of some of the less stable amino-acids, which are essential to normal nutrition. Digests so prepared are of only limited use for intravenous or oral administration unless they are enriched by additions of the destroyed essential amino-acids, which greatly increases their cost. The use of these digests

for accurate analysis of the original protein is also obviously impaired by the destruction incident to hydrolysis.

It has now been discovered by research associates of the Textile Foundation at the Bureau, that in the presence of certain dyes and ions derived from acids of high molecular weight, proteins are hydrolyzed at 65° C. over 100 times as fast as when they are hydrolyzed by dilute solutions of hydrochloric acid alone. A rapid rate of hydrolysis is attained under considerably milder conditions than those customarily employed.

In RP1503 in the November *Journal of Research*, Jacinto Steinhardt and Charles H. Fugitt point out that the catalytic action of the effective ions is suggestively similar to the action of enzymes in digesting proteins. The experiments show that the catalytic effect depends on the ability of the ions to combine with groups in the proteins near the bonds that are attacked. This demonstration is used as the basis for proposing a theoretical mechanism of the acid digestion of proteins. Practical applications are suggested.

WEAR TESTS OF CARPETS.

Carpets and rugs form one of the most important items of home furnishing. They should harmonize with the decorative scheme of the room, conform to the general architecture of the house, and appeal to the æsthetic demands of the occupants. Since they constitute a more or less permanent fixture, durability should be a primary consideration in their selection.

The evaluation of the durability of carpets and rugs has been thoroughly studied at the Bureau. The results of several years of tests are reported in RP1505 by Herbert F. Schiefer in the November *Journal of Research*. Two types of machines for testing the wear resistance of carpets, known as the NBS and the Shawmut machines, are described. Factors affecting the results of the wear tests were studied, and the effect of systematic changes in carpet construction on the wear resistance was investigated with each machine. Tests on 24 carpets of Axminster, velvet, and Wilton weaves were

made on the two types of machines in several laboratories, and the results obtained in the different laboratories were compared with each other and also with the results of 3 years of severe service tests on the same carpets. The service tests were conducted in a corridor of the Federal Warehouse, Washington, D. C. Over 2,000,000 persons walked over the carpets during these tests. Three types of vacuum cleaning systems were used, and their effect on the wear of the carpets and the effectiveness of cleaning were observed. Three different wear indices for evaluating the relative wear of carpets were considered. The nature of the wear produced by the two machines on the pile fibers of carpets was found to be similar to that produced during the service tests. The excellent correlation between the results of the machine tests and the tests in service is highly significant, and shows that the relative wear of carpets can be evaluated by means of laboratory tests. However, for interlaboratory comparison, the testing machines and the testing procedures must be rigidly standardized and controlled.

EFFECT OF CALCIUM CHLORIDE ON CONCRETE.

A study of the effect of calcium chloride on the strength of concrete made from mixes of low water content was completed a short time ago by J. C. Yates and C. R. Cornthwaite, research associates of the Calcium Chloride Association. The following abstract is based on a paper which they have prepared for the Highway Research Board.

Compressive strength data were obtained on concrete cylinders prepared in the laboratory from mixes having water contents of 6.5 to 3.5 gallons per bag of cement and containing 0, 1, and 2 per cent. of calcium chloride. Increasing the amount of calcium chloride resulted in increasing the strengths of the concretes, particularly at the earlier ages.

Strength measurements were made also on concrete block and pipe prepared with and without calcium chloride at a local concrete-products plant. In these experiments the mix (containing approximately 3 gallons of water per bag of cement) was the same as that regularly used at this plant for both

products. Furthermore, the plant practices of mixing, molding, and curing were followed. Additions of calcium chloride increased the compressive strength of the block and the crushing strength of the pipe.

SIMPLIFIED PRACTICE RECOMMENDATION FOR FORGED AXES.

As part of its broad program of simplification to conserve metals and materials by the elimination of non-essential types and sizes of commodities, the War Production Board requested the Bureau to work out a further simplification of the line of forged axes shown in Simplified Practice Recommendation R158–41.

Therefore, last June a proposed revision was prepared which, with some amendments, was approved by the Forged Ax, Hatchet, and Hammer Industry Advisory Committee, and issued by the War Production Board as part of Schedule II of Limitation Order L-157, Hand Tools Simplification, effective from November 17, 1942. It was also approved as an emergency revision of Recommendation R158–41.

Under the revised program, 150 varieties of axes (counting patterns, styles, grades, and sizes) may be manufactured, instead of the 382 varieties which the industry has been producing. This represents a reduction of 61 per cent. The smaller number of types and sizes permitted will tend to speed up production, eliminate inventories of special sizes and shapes of steel, and bring about a more rapid rate of turnover of finished products, with inventories reduced to a minimum. The use of all alloy steels will be eliminated.

After the emergency, Recommendation R158 will again be subject to regular review for revision or reaffirmation by the standing committee.

Electronic "Eye" Records Ultraviolet in Sunshine.—(*Refrigerating Engineering*, Vol. 44, No. 3.) Sensitive new electronic "eyes" developed by Westinghouse engineers to see and record invisible ultraviolet rays in sunshine will soon begin their first daily measurements of "sunfall" in the United States to study its effect on the wartime health of the nation. The new sun-measuring instruments eventually will operate in 20 of the world's first solar observation posts to be set up for a nationwide ultraviolet study by the United States Weather Bureau. Located in Weather Bureau stations, the observation posts will be scattered over a 1,000 mile stretch of land running from Texas northward through the Mississippi Valley to the colder regions of the Midwest. First, sun metering will get under way soon at Central Park and LaGuardia Field in New York City and in Boston and Cambridge, Mass., to record the amount of ultraviolet which penetrates through the haze of big metropolitan centers. These figures may eventually make it possible to forecast for several days in advance the intensity of sunfall over a city, Weather Bureau officials believe. Development of a new electronic light cell in the meters will make sunfall measurements as accurate and uniform as the familiar rainfall statistics now issued by the Weather Bureau, according to Dr. H. C. Rentschler, director of the Westinghouse lamp research laboratories at Bloomfield, N. J. Sun tan ultraviolet striking the metal cell will be converted into millionths of watts of energy inside a long glass tube. As it is absorbed in the cell, each quantity of energy will register as a click on an automatic counting machine to give a total amount of radiation for any given period of time. Sun statistics taken from various climate zones and compared with the health statistics of those zones will be one way in which research men can study the effect of ultraviolet on humans. Such studies could be aimed at determining what preventive or curative effect, if any, sunlight has on such diseases as tuberculosis and rickets and the relationship between exposure to ultraviolet and health.

R. H. O.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING OF THE INSTITUTE, WEDNESDAY, NOVEMBER 18, 1942.

The stated monthly meeting of The Franklin Institute took place at 8:15 P.M., Wednesday, November 18th, in the Hall of the Institute.

The audience stood at attention during the playing of the national anthem. The meeting was then called to order by the President, Mr. Charles S. Redding.

It was stated that the minutes of the last meeting, printed in full in the November JOURNAL OF THE FRANKLIN INSTITUTE, would be approved if no objection were offered. They were approved as printed.

Dr. Henry Butler Allen, Secretary and Director of the Institute, was asked to report.

Dr. Allen stated that the activity of the Membership Department was responsible for the following additions to membership:

Active Life	1
Sustaining	5
Active Family	4
Active	88
Active Non-Resident	6
Associate Family	4
Associate	38
Student	32
Library Sustaining	12
Total	190

He then announced that the Christmas Week Lectures, to be held at 3 P.M. on Monday, Tuesday and Wednesday after Christmas, would be psychological in nature this year, accompanied by demonstrations, and would be entertaining as well as instructive. The lecturer will be John R. Roberts, Director of the Training Acceptance Center of the United States Office of Education and the Philadelphia School District. His subject will be "Your Place in the World of Tomorrow."

It was suggested that tickets for this series of lectures would make nice Christmas gifts, the price being $1.00, plus the war tax.

The Secretary then called to the attention of the audience the fact that a new series of musical lecture-recitals have been inaugurated to replace the Marriner lectures which have proved so popular for the last eight years. Mr. Marriner is now in the Army of the United States.

The Chairman then introduced Dr. Ellice McDonald, who gave a "Report on the Work of the Biochemical Research Foundation of The Franklin Institute," of which he is Director.

Dr. McDonald pointed out that much of the work of the laboratories could not be discussed because of censorship. He stated that the facilities of the laboratories and the abilities of the staff were all devoted to the war effort. His report will be published in full in the JOURNAL OF THE FRANKLIN INSTITUTE.

The Chairman expressed appreciation to Dr. McDonald for the splendid work carried on under his direction and then dismissed the meeting with a rising vote of thanks for his interesting paper.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, November 11, 1942.)

HALL OF THE COMMITTEE,
PHILADELPHIA, NOVEMBER 11, 1942.

MR. JOHN B. KLUMPP *in the Chair.*

The following report was presented for final action:

No. 3103: Work of Charles M. Allen.

This report recommended the award of an Elliott Cresson Medal to Charles Metcalf Allen, of Worcester, Massachusetts, "In consideration of his origination of the Salt Velocity Method for the measurement of the flow of water in conduits and for his contributions to the Science of Hydraulics."

JOHN FRAZER,
Secretary to Committee.

LIBRARY NOTES.

The Committee on Library desires to add to the collections any technical works that members would wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print 9 × 14 inches is thirty-five cents.

The library and reading room are open on Mondays, Tuesdays, Fridays and Saturdays from nine o'clock A.M. until five o'clock P.M., Wednesdays and Thursdays from two until ten o'clock P.M.

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NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

The Effect of Drying from the Frozen State on the Physico-Chemical Properties of Citrated Human Blood Plasma.—LAURA E. KREJCI. A physico-chemical investigation of the effects of drying by evaporation from the frozen state has been made on a sample of pooled citrated normal human blood plasma, obtained through the courtesy of Dr. Murray Wright from the blood bank of the Jewish Hospital of Philadelphia. Approximately 80 per cent. of the plasma was dried by Mr. L. D. Smith by evacuation of thin frozen layers; the light porous residue, which constituted 8.0 per cent. of the weight of the plasma, was stored at atmospheric pressure at 3° C. The remainder was stored at 3° C. without further treatment and reserved for control experiments.

The pH of the untreated plasma, measured by Mr. L. D. Smith, was about 0.4 above the normal pH of the blood, probably because of spontaneous escape of carbon dioxide. The pH (also measured by Mr. Smith) of the plasma reconstituted by addition of the required weight of water to the dry residue was almost two units higher than blood pH (Table 1). The removal of carbon dioxide during evacuation is believed to be responsible for the increased alkalinity.

The fresh plasma and the redissolved plasma were examined by means of the Tiselius electrophoresis technique (Tiselius, *Transactions of the Faraday Society*, **33**: 524, 1937)

TABLE 1.

	pH of Plasma (Before Dialysis).	Specific Conductance after Dialysis of 11 cc. of Plasma against 1500 cc. of Buffer.	
		Plasma.	Buffer.
Fresh plasma	7.85	7.74×10^{-3} ohms^{-1}	9.05×10^{-3} ohms^{-1}
Lyophile plasma	9.25	7.32×10^{-3} ohms^{-1}	8.52×10^{-3} ohms^{-1}
	9.25	7.38×10^{-3} ohms^{-1}	8.54×10^{-3} ohms^{-1}
		7.35×10^{-3} ohms^{-1}	8.45×10^{-3} ohms^{-1}

for possible changes in the protein constituents. Previous to electrophoresis eleven cc. of the undiluted fluid were dialyzed against 1500 cc. of a buffer solution of pH 8 containing 0.15 M NaCl and 0.02 M phosphates. The specific conductances of the redissolved plasma after dialysis and the buffer solution against which it was dialyzed were lower, respectively, than the specific conductances of the dialyzed

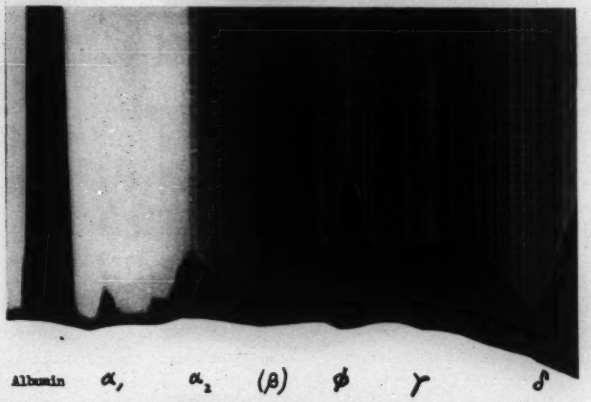


FIG. 1. Electrophoretic pattern for pooled undiluted citrated human blood plasma (untreated) after migration for 9 hours at a potential gradient of about 5 V./cm. and 11 hours at a potential gradient of about 0.6 V./cm. Ascending boundaries. pH 8, 0.15 M NaCl, 0.02 M phosphate. The β globulin boundary is obscured by the ground glass flange plates at the junction of the two halves of the cell.

fresh plasma and its dialysate (Table 1). These differences are probably due to loss of carbonate during evacuation.

The electrophoretic pattern of the untreated plasma, recorded by the Longsworth method (Longsworth, *Journal of the American Chemical Society*, **61**: 529, 1939), was normal (Fig. 1). After prolonged electrophoresis the ascending α_2 globulin boundary was resolved into two constituents. Most of the opalescence possessed by the plasma migrated with the peak of the α_2 globulin boundary (Fig. 2*a*, 3*a*); a small frac-

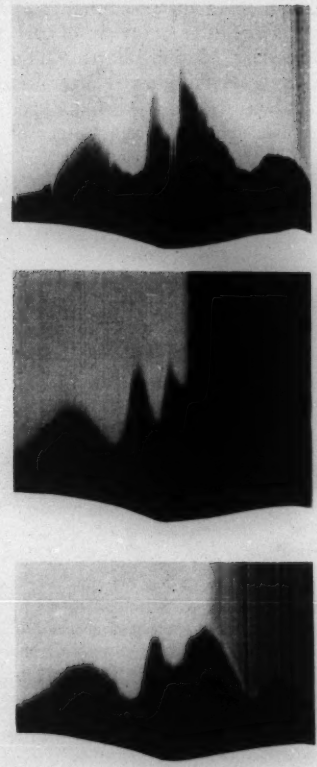


FIG. 2. The globulins of pooled undiluted citrated human blood plasma after migration for 9 hours at a potential gradient of about 5 V./cm. Descending boundaries. (*a*): Untreated. (*b*): Frozen, dried, and redissolved (turbid). (*c*): Frozen, dried, and redissolved (centrifuged clear). pH ·8, 0.15 M NaCl, 0.02 M phosphate. From left to right (slowest to fastest migration rates) the peaks represent γ globulin, fibrinogen, β globulin, and α globulin.

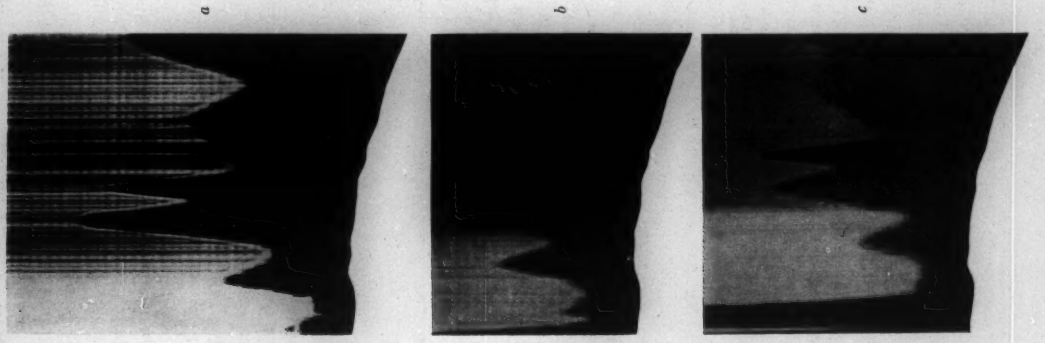
tion of it, visible only in the cathode (descending) arm of the U-tube (Fig. 2*a*), moved with the leading edge of the β globulin boundary.

The reconstituted plasma was turbid (Scudder, *Annals of Surgery*, **112**: 502, 1940; McFarlane, *Nature*, **149**: 439, 1942; Medinger, p. 65, "Blood Substitutes and Blood Transfusion," edited by Mudd and Thalhimer, Charles C. Thomas, Publisher, 1942) and the photographic record of the electrophoretic pattern was consequently incomplete. During dialysis a few very small fibrin clots were formed; they settled under gravity and were discarded. The turbidity coincided with the leading portion of the β globulin boundary; it obscured all boundaries in advance of it in the cathode (descending) arm of the U-tube (Fig. 2*b*) and all boundaries which followed it in the anode (ascending) arm (Fig. 3*b*). The appearance of the descending β globulin boundary was changed; the sharp peak adjacent to the fibrinogen boundary was reduced in height and sharpness. In all other details which were visible, the plasma pattern appeared to be the same as before drying.

An effort was made to reduce the turbidity of the reconstituted plasma by minimizing the opportunity for surface denaturation around air bubbles trapped during the process of solution; air was removed by evacuation of the dry residue, and the water was added under vacuum. This procedure appeared to reduce somewhat the formation of small fibrin clots, but the turbidity was undiminished, and the electrophoretic pattern agreed in all details with that for plasma redissolved at atmospheric pressure.

A sample of Sharp and Dohme Lyovac horse serum, which is sealed off under vacuum, and from which presumably air should be more completely removed than is possible by reëvacuation after admission of air, gave an even more turbid solution than the human plasma redissolved without evacuation of the solid. Bubbles of air trapped in the solution are apparently not responsible for the turbidity.

On centrifugation of the redissolved human plasma, the suspended matter was thrown to the surface. It was subjected to microchemical analysis by Dr. Alfred Bloch and found to contain protein and fat, part of which was cholesterol,


a
b
c

but it appeared to be predominantly protein. The electrophoretic pattern of the cleared plasma differed from that of the fresh plasma in the reduced concentration of β globulin (Fig. 3, *a* and *c*), the contour of the descending β globulin boundary, and the rate of migration of the residual opalescence. The sharp peak of the descending β globulin boundary, adjacent to the fibrinogen boundary, was missing, and the boundary as a whole was approximately symmetrical (Fig. 2, *a* and *c*). Most of the residual opalescence occupied the same relative position in the electrophoretic pattern as the turbidity in the pattern for uncentrifuged lyophile plasma; a small fraction of it, visible only in the anode (ascending) arm of the U-tube, moved with the more rapid rate of migration characteristic of most of the opalescence in the fresh plasma.

The demonstration that fats constitute part of the suspended matter in reconstituted plasma suggested the possibility of reducing the turbidity by the use of plasma of lower fat content. A rabbit was fasted for twenty-four hours, then bled by cardiac puncture. The plasma (citrated) was brilliantly clear. After freezing, drying, and redissolving, it was opalescent but contained no fibrin clots. The suspended matter rose to the surface on centrifuging and probably consisted of fats and protein also. The turbidity of lyophile plasma can be reduced, therefore, but not wholly eliminated, by the use of blood drawn during fast.

Freezing for two and one-half hours in solid carbon dioxide and acetone (without subsequent drying) caused no change in the appearance of the fasting-rabbit plasma. The cloudiness which frequently develops after freezing to low temperatures (McFarlane, *op. cit.*) can apparently be eliminated, therefore, by the use of plasma obtained from blood drawn during fast.

FIG. 3. The globulins of pooled undiluted human blood plasma after migration for 5 hours at a potential gradient of about 5 V./cm. Ascending boundaries. (*a*): Untreated; from left to right (fastest to slowest migration rates) the peaks represent α_1 globulin, α_2 globulin, β globulin, fibrinogen, γ globulin, and the δ boundary. (*b*): Frozen, dried and redissolved (turbid); from left to right the peaks represent α_1 globulin and α_2 globulin. (*c*): Frozen, dried, and redissolved (centrifuged clear); aside from the incomplete peak at the left (which represents the albumin) the order of the constituents is the same as in (*a*). pH 8, 0.15 M NaCl, 0.02 M phosphate.

An effort was made to determine the mobility of the particles normally formed after freezing to low temperatures, using human plasma which had been freshly prepared to avoid confusion with the turbidity which develops on standing, and refreezing after dialysis so that the electrophoresis cell could be filled immediately after thawing. Before the protein boundaries were adequately separated, however, the precipitate was completely redispersed.

After storage for six months at 3° C. the frozen rabbit plasma was found to have jellied to a tenuous clot; the reconstituted lyophile rabbit plasma had jellied to a firm clot, and the untreated rabbit plasma was still fluid. It appears that some phase of the clotting mechanism, which is initiated or promoted by freezing alone, is further promoted by the processes of drying and redissolving.

On the other hand, the lyophile human plasma, which was not obtained from fasting subjects, developed a few small fibrin clots soon after redissolving, then remained fluid for a year. The electrophoretic pattern obtained after diluting this plasma with four volumes of buffer solution differed from that of the freshly dissolved plasma chiefly in the details resulting from the use of a more dilute solution. There appeared, however, to be a slight increase of α globulin and fibrinogen and a slight decrease of β globulin.

McFarlane (*op. cit.*) has shown that the opalescence which gradually develops in filtered human serum is mainly lipid, and that large amounts of lipids, which are ordinarily stable to ether extraction, can be extracted by freezing the serum-ether mixture to $-25°$ C. or lower. Serum exhaustively freed from lipids by McFarlane's procedure gives an electrophoretic pattern which differs from that of the untreated serum only in the reduced concentration of β globulin; it remains permanently clear, even after freezing, drying, and redissolving. "Much of the β globulin of human serum is a lipoid—β globulin complex so oriented that the protein determines the surface properties of the complex; or, alternatively, . . . β globulin itself is a compound of lipoid and a serum protein, having surface properties different from those of its constituents" (McFarlane, *op. cit.*). The cloudiness of serum

which has been frozen to − 23° C., the temperature at which it becomes truly solid (McFarlane, *op. cit.*), and the milkiness of redissolved serum after freezing and drying, led McFarlane to suggest that the association of the lipoid with protein depends upon the presence of liquid water, and that freezing destroys this association.

The complete absence of turbidity from lipoid-impoverished plasma (i.e., plasma obtained from blood drawn during fast) after freezing to low temperatures appears to be consistent with the hypothesis that the cloudiness usually observed after this treatment is caused by lipoids liberated from the lipoid-protein complex by removal of liquid water. There is further agreement with McFarlane's conclusions in the electrophoretic evidence that the suspended matter in lyophile plasma originates from the β globulin fraction, and in the microchemical proof that it contains lipoids. The cloudiness of lyophile plasma, however, is greater than that of plasma which has been frozen to low temperatures and thawed. It is permanent, while the cloudiness of plasma which has been frozen disappears soon after thawing. It may result in part from the liberation of lipoids by removal of liquid water, but the suspended lipoids appear to be augmented and stabilized by some additional factor.

When water is added to the dried plasma, sufficient heat is evolved to cause a perceptible rise in temperature.* In a rough experiment, the addition of the first 0.5 cc. of water (at 29.5° C.) to 0.96 g. of dried plasma (at 32.5° C.) caused the temperature (measured with a micro-thermometer initially at 32.5° C.) to rise to 33.5° C. This temperature was maintained during the addition of a further 0.25 cc. of water. Subsequent additions of water (10 cc. in all) led to a gradual drop in temperature to 30° C.

This suggests that fairly intense local heating may occur when water comes into contact with the dry plasma residue. The greater, more permanent turbidity of lyophile plasma may be the result of slight protein denaturation, or of interaction between certain of the lipoids and certain of the pro-

* Heat effects have been observed by Cohn (Chemical Reviews, 28: 395, 1941) during solution of certain dried plasma fractions.

teins, caused by the transitory rise in temperature which accompanies reconstitution of the plasma.

The Influence of Non-Specific Protein on the Heat Inactivation of Antibody to Pneumococcal Polysaccharide. I. Effect of Various Proteins on the Heat Stability of Antibody.—ROBERT K. JENNINGS and LOUIS DESPAIN SMITH (*Journal of Immunology*, **45**: 105, 1942). Water-insoluble globulin from a sample of Type I antipneumococcal horse serum was found to be more heat resistant than the parent serum as regards retention of specific precipitability. Restoration of the serum components removed in purification, or addition of whole serum to the water insoluble-globulin solution, resulted in mixtures which were inactivated under conditions which did not inactivate the antibody alone. Heating the water-insoluble globulin and the other serum components separately before mixing did not interfere with specific precipitation. The ability to assist in heat inactivation of antipneumococcal antibody appeared to be a property associated primarily with the non-antibody serum globulin. Casein, also, possessed this property to a marked degree. Gelatin, albumin, myogen, pectin, gum arabic, and heterologous polysaccharide had no effect upon the heat-inactivation of antibody.

The Influence of Non-Specific Protein on the Heat Inactivation of Antibody to Pneumococcal Polysaccharide. II. The Electrophoretic Investigation of the Heat Inactivation of the Antibody in the Presence of Casein.—LAURA E. KREJCI, ROBERT K. JENNINGS, and LOUIS DESPAIN SMITH (*Journal of Immunology*, **45**: 111, 1942). The electrophoretic patterns of casein and of the antibody to Type I pneumococcal polysaccharide were practically unaltered by heat treatment of the individual solutions. Heat treatment of a mixture of these two substances led to loss of precipitability of the antibody by the homologous polysaccharide and to a change in the electrophoretic pattern. Part of the alpha casein and part of the antibody (gamma globulin) migrated with the beta casein after heat treatment; this change appeared to result from interaction of the two constituents after partial de-

naturation. The interaction was probably responsible for the inactivation. Precipitative tests on the fractions separated by electrophoresis of the unheated mixture afforded additional evidence that alpha casein is the constituent responsible for the inactivation of the antibody. By electrophoretic fractionation of the heated mixture it was possible to separate the antibody of unchanged mobility from that which had been modified by heat treatment. Under these conditions the unchanged antibody was still precipitable by polysaccharide.

BOOK REVIEWS.

PHOTOGRAPHY, Its Principles and Practice, by C. B. Neblette. Fourth edition, 865 pages, illustrations, 16 × 24 cms. New York City, D. Van Nostrand Company, Inc., 1942. Price $7.50.

Neblette's Photography needs no introduction to the photographic profession. For many years, in fact since the first edition of 1927, it has been the leading book both in the way of a text as well as a reference work to those seeking theory and information on practical methods. It has been used by amateur and professional with equal satisfaction. And, now, the fourth edition makes its appearance. This edition reflects the progress of photography in several ways. One of them is the increasing complexity of the subject as is shown by the inclusion in the book of many things which were not in earlier editions. Another is the assumption of a broader background of scientific training.

The book is divided into sections which facilitate understanding, reference work, and an orderly knowledge of the subject as a whole. The first section is on the history of photography, and succeeding this, the optics of photography is taken up. Under this heading, there is a concise summary of the principal types of photographic objectives in use today and treatments on the camera and light sources. The theory of the photographic process begins with a study of the chemical changes produced by radiation and proceeds through the photographic emulsion, developing agents and solutions, and a very interesting part on the structure of the developed photographic image. The study of sensitometry precedes the photographic reproduction of tone and color in monochrome. The negative process is described including materials, exposure development, and treatment. Similarly, positive processes are given consideration. The last section is devoted to photography in color, where are described principles of three-color photography, subtractive paper printing processes, screen and lenticular processes, and accuracy of color reproduction.

There is a wealth of information in this book. It is ably presented for use as a text, as a source of general and specific information, and as a reference.

R. H. OPPERMANN.

NATURAL HISTORY WITH A CAMERA, by L. W. Brownell. 292 pages, illustrations, 16 × 24 cms. Boston, American Photographic Publishing Company, 1942. Price $3.75.

This book should be a delight to those who love the great outdoors. It combines instruction in photography with a knowledge of plants and animals that is informative, interesting, and inspiring. The author, who is nature editor of the periodical, American Photography, is well qualified in experience, as a writer, naturalist, and photographer to present such a book, and a glance through the pages of this book confirms that he knows all of the good tricks as well as the bad. With regard to the latter, in the very beginning of the book, in a chapter on equipment, the author makes mention of the dishonesty of some photographers,

impatient to get results, who resort to trickery and subterfuges to obtain photographs with seemingly natural settings.

The book reveals that the necessary outfit for a nature photographer, at all events for one who is just starting in this field of activity, is neither extensive nor expensive. This does not mean that the best work can be done with cheap implements or without proper accessories. The author is very frank on what is needed for different kinds of work, in the light of his extensive experience. After this discussion on the equipment of the nature photographer, the book is divided into chapters on the months of the year. They begin with the month of March in order to follow nature when spring begins. It tells of how and where to look for signs of life in the woods and fields and describes the nature and habits of plants and animals. While much is left to the discretion of the reader on what to photograph, suggestions given in the book help tremendously. Succeeding chapters are each devoted to a month of the year and similar treatment is given.

The book is well illustrated and there is a useful name index in the back. The method of presentation is excellent. Even a glance through the book is interesting and impressive.

R. H. OPPERMANN.

POISSON'S EXPONENTIAL BINOMIAL LIMIT, by E. C. Molina, First edition, 47 pages, tables, 20 × 28 cms., New York, D. Van Nostrand Co., Inc., 1942. Price $2.75.

The author, Switching Theory Engineer of the Bell Telephone Laboratories, Inc., states that Poisson's Exponential Binomial Limit has been used in the Bell Telephone System since the early 1900's in the solution of problems of telephone trunking. In 1938 tables as high as $a = 100$ were reproduced by an off-set process for the convenience of the System's engineers who were concerned with switching and traffic problems. These tables have come to the notice of engineers and scientists outside the system and in response to several requests are now made publicly available. The tables are useful in many other ways. One of them, the application to inspection problems like the probability of finding x defective units in a random sample of n is shown in a brief statement by Mr. H. F. Dodge, Quality Results Engineer. The book contains a table of individual terms of the Poisson Formula, $\frac{a^x e^{-a}}{< x}$, and cumulative terms of the Poisson Formula, $= \sum_{x=c}^{\infty} \frac{a^x e^{-a}}{< x}$.

R. H. OPPERMANN.

NATURAL TRIGONOMETRIC FUNCTIONS, by Howard Chapin Ives, C.E., Second edition, 351 pages, tables, 18 × 25 cms., New York, John Wiley & Sons, Inc., 1942. Price $9.00.

This second edition gives the changes of the tangents and cotangents for angles of 0° to 2° to single seconds which is the principal feature of this edition over the first edition. The book is divided into two parts of which the first consists of the above and some 270 pages devoted to the seven place natural sines, cosines, tangents and cotangents to ten seconds, together with proportional parts to seconds. The second part consists of miscellaneous tables such as the length of arc to radius unity, the coefficient K for central angles of certain curves, radii,

functions of a 1° curve and corrections to tangent distances and to external distances. As a means of reminder or for refresher purposes there are briefly given methods of defining trigonometric functions, together with formulas and solutions of triangles, and other useful information.

The book appears at a time when its content was never of greater importance. It will find a place with users of varied interests.

R. H. OPPERMANN.

THE FUTURE OF TELEVISION, by Orrin E. Dunlap, Jr., First edition, 194 pages, illustrations, 14 × 22 cms., New York and London, Harper & Brothers, 1942. Price $2.50.

Here is another book by the former radio editor of the *New York Times*. He states that $30,000,000 have been spent since 1925 in research in television and now the industry is on the threshold of practical application in tremendous proportions. There is great need for men and women of a multitude of crafts and skills to make a success of television. With this in mind the aim of this book is to gather in the pieces and put them together in a story of the new industry, to serve as a guide and to help those seeking careers and opportunities in this fascinating field.

Aided by using some past history as a background the story opens with a brief survey of what television is, its physical capabilities and some reference to its commercial possibilities. This leads to the awakening of public interest and the opening of the first station. The economics of television for the home is considered and the effect on home life, as is the type of programs and the effect of television on the movies. With regard to the latter the stand is taken that television must offer a continuous performance that is new. This is paced by radio precedent and is in contrast to the motion picture theater style of program. There is considerable discussion on television and the theater and the outlook for broadcasting, out of which are drawn sketches of possible types of television programs. These include sports and news events in photos, and the educational side. The last part of the book is on the evolution of television and a description of how the radio eye sees.

The story is well written. It holds interest. It is a source of general information as well as specific information valuable to those who may become interested in this field.

R. H. OPPERMANN.

ELECTRICAL COUNTING, by W. B. Lewis, M.A., Ph.D., 144 pages, illustrations, 14 × 22 cms., London, University Press, 1942. Price $2.50.

Individual atomic and subatomic particles may be detected if they are electrically charged and possess sufficient kinetic energy. When such particles pass through matter, the electric charge produces mechanical forces sufficient to disrupt the electronic configurations of the atoms through which they pass. A trail of charged atoms or ions is therefore left in the wake of the swiftly moving particle. One method of observing this trail of ions is by its electrical effect, and it is with this general method that this book is exclusively concerned.

The treatment opens with a brief reference to ionization by single particles and proceeds through descriptions of ionization chambers and amplifiers. Next a

description is given of an electro-mechanical oscillograph for photographic records before an addition to the section on amplifiers, namely the principle of feedback and stabilization, and further the consideration of non-linear characteristics of valves which are applied, for example, to the mixing circuit of a coincidence counting system. Various types of recording counters are described including the Geiger-Müller tube counters of which special mention is made and which operates by the production of an electrical discharge in a gas. Of importance in the interpretation of counts of particles are the statistics of a random distribution, which exists often when the distribution in time of particles arises from the decay of a long-lived radioactive substance. Accordingly consideration is given these statistics. The last chapter is devoted to energy determinations from range measurements. In all there are some 139 pages to the book. The treatment is clearly presented and should be of value to those interested.

R. H. OPPERMANN.

LECTURES ON MACHINE DESIGN, by Lewis F. Moody, illustrations, 75 pages, 21 × 27 cms., Ann Arbor, Michigan, Edwards Brothers, Inc., 1942. Price $1.75.

This 75 page lithoprinted book is directed primarily to the application of the principles of the Mechanics of Materials to the more usual forms of machine members, and to the extension of those principles to special cases and problems which are of importance in the design of machinery. At the outset an analysis is made of the "factor of safety," and an examination is made of its components so that a more clear conception is obtained of this factor when used as a divisor with the ultimate stress of the material for determining working stress. Simple tension, compression and shear are next discussed, which is followed by deflection of beams and stress in a ring. This leads to columns and combined stresses. A very interesting, important and even somewhat unusual consideration is that given in connection with shafts, to lateral vibration through the flexure of the shaft. Likewise a useful discussion is that on internal and external pressure of cylinders in the last part of the book. The work is well illustrated with diagrams and should prove of value to those qualified to follow it.

R. H. OPPERMANN.

THE NATIONAL PAINT DICTIONARY, by Jeffrey R. Stewart, Second edition, 224 pages, illustrations, 24 × 31 cms. Easton, Laros Printing Company, Inc., 1942. Price $7.50.

The prevention of misunderstanding can largely be accomplished by exact definition. This is not always possible, but in the application of science there is much that can be done. The result not only facilitates understanding but goes a long way toward standardization of language. The paint industry is a field where specific meanings have the utmost effectiveness and the National Paint Dictionary has endeavored to fill this need. The former edition has established its reputation for dependability and comprehensiveness. This second edition has been made necessary by the expansion of the industry.

The book is not the work of one man only. The author secured the help of a number of individuals prominent in the paint industry for information on technical definitions. Also, many books and directories have been used. There are

some 142 pages devoted to definitions of terms and materials, including an addendum where there are listed several additional definitions which were compiled too late to include in the many sections. The definitions are arranged alphabetically by name, and in many cases contain quite extended information including illustrations, specifications, different gradings, properties, advantages and disadvantages, etc. There is no table of contents to indicate the sections of the book, so that when using the definition section, it must be kept in mind that there is an addendum, and also what appears later in the book, a supplement containing a great deal of useful information. This begins on page 147 and continues for some 69 pages. An index to the supplement appears on page 148. Contained in the supplement are tables of temperature conversion, flash points of oils and volatile liquids, color identification tests for pigments, data on drying oils, vapor pressures, properties of terpene and rosins, etc.

People interested in the subject will find the book valuable. Only a thumbing through of the pages need be done to establish this fact.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Reading as a Visual Task, by Matthew Luckiesh and Frank K. Moss. 428 pages, illustrations, 15 × 22 cms. New York, D. Van Nostrand Company, 1942. Price $5.00.

The Pirotechnia of Vannoccio Biringuccio, Translated from the Italian with an introduction and notes by Cyril Stanley Smith and Martha Teach Gnudi. 476 pages, illustrations, 20 × 27 cms. New York, The American Institute of Mining and Metallurgical Engineers, 1942.

A–C Calculation Charts, by R. Lorenzen. 146 plates, illustrations, 25 × 31 cms. New York, John F. Rider Publisher, Inc., 1942. Price $7.50.

Frequency Modulation, by August Hund. First edition, 375 pages, illustrations, 16 × 24 cms. New York and London, McGraw-Hill Book Company, Inc., 1942. Price $4.00.

CURRENT TOPICS.

National Inventors Council Has Considered 91,823 Inventions, Chairman Kettering Announces at Schenectady Meeting.—A new peak in American inventiveness has been reached, DR. CHARLES F. KETTERING, Chairman of the National Inventors Council, announced recently upon the occasion of the Council's meeting at the General Electric Company. Patriotic Americans, many of them non-professionals, have submitted to date 91,823 suggestions which they believe will help the Army and Navy in winning the war. In a two-day meeting of the National Inventors Council, a government agency under the Department of Commerce, the most recent and promising of these inventions were discussed and evaluated preliminary to making them available to the armed services. "Ideas have been welcomed from amateurs because their suggestions in many cases prove fruitful and of practical use," Dr. Kettering said. Often 500 to 1000 inventive ideas are received in a day at the Washington Offices of the National Inventors Council. Dr. William D. Coolidge, director of the General Electric Research Laboratory is a member of the Council, which consists of 14 other leaders in industry and science.

R. H. O.

Electronic Robot Measures Creep of Metals.—An electronic robot, including an electric eye, now measures the rate at which metals flow when heated and stressed in the General Electric Research Laboratory in Schenectady, N. Y. Not only does this release for other important work the attention of a man who formerly watched the metal sample through a microscope; it is also more sensitive than any human observer and more reliable. It watches all day without ever getting tired. These measurements of the "creep" or flow of materials are being made by DR. SAUL DUSHMAN, assistant director of the Laboratory. Since a steam turbine, for example, operates with greater efficiency the higher the temperature, metallurgists try to create alloys for parts which will hold their shape under high stress and the greatest possible operating temperatures. Last year Dr. Dushman described an accelerated method for making creep tests. The usual test uses a bar of the sample metal, which is heated in a special furnace to the range of operating temperatures (800°–1400° F.). Such tests may

require months to complete. The new method uses a thin wire of metal, and passes an electric current through it, to heat it to perhaps 2000° F. This is enclosed in a glass cylinder, which protects it from air currents, and even permits the tests to be made in an atmosphere of nitrogen, thus preventing rusting from the oxygen in open air. A weight is attached to the wire. Through a microscope focussed on the lower end the observer formerly watched and measured the slow stretching, as much as a half of a per cent. an hour. Data are obtained rapidly by this method. To make the measurements automatically, J. T. Mireles Malpica, Mexican-born engineer of the G-E General Engineering Laboratory, devised the robot, and the apparatus now used was constructed by Eric T. Asp, of the Research Laboratory. This device has not yet been placed in production for commercial use. The principle may be demonstrated with a flashlight and two combs. Hold one comb over the lens of a flashlight, and you can shine a spot of light on a neaby wall. Now hold the other comb over the first, close to it with teeth parallel and move the second comb very slowly. When the teeth of one cover the openings of the other, the light is cut off. But when the second comb moves the width of a tooth, the clear spaces are lined up and light passes through. If the flashlight and first comb were firmly fixed, and the width of the teeth and openings were known, it would easily be possible to measure the movement of the second comb merely by counting the alternations of light and dark. This is exactly what Mr. Mireles Malpica did. A light shines through a glass grid, ruled with horizontal black lines each 1/250 inch wide and the same distance apart. Attached to the bottom of the test wire is another such grid, nearly in contact with the first. A lens forms an enlarged image of the grids on the surface of the photocell, which converts light into electricity. A very sensitive meter, in which electronic tubes are used, makes in ink on a moving strip of paper a record of the changes in current from the photocell, hence in the changes in brightness or the movement of the second grid. In this way it is possible to measure accurately an extension of the wire as small as 1/10,000 inch.

R. H. O.

Two Million Documents Recorded on Microfilm.—(*Power Plant Engineering*, Vol. 46, No. 9.) Through the use of microfilming equipment a story of the electrical industry's growth since the early 1880's is being transferred from two million sheets of old Irish linen and drawing paper to movie film at the Westinghouse East Pittsburgh works. An acre of storage space will be cleared for

productive use and a more efficient record system set up by reducing the size of tons of permanent records. When recorded on film, documents which now occupy more than an acre in floor space can be stored in a vault about 10 feet square. More than two million of these documents will be photographed during this 2-year project. To be put on 16 or 35 mm. movie film, depending on size, are records ranging from 5 in. cards to 5 ft. drawings. Records of typing paper size or smaller are fed into an automatic camera machine which snaps the pictures at an average rate of 35 per min. Larger ledger sheets, engineering drawings, and tracings are photographed by a 35 mm. camera suspended above a table. The distance between camera and table is automatically adjusted to the proper focus. Old shop orders, sketches, drawings and charts which have accumulated from the time the company was organized 56 yrs. ago are all being photographed. Plans and sketches of the first alternating current equipment produced in America in 1885, the early generators that harnessed Niagara Falls in 1896, the first electrical apparatus to drive ships in 1912 are being taken from the archives.

R. H. O.

Underground Gas Storage Advocated.—(*Gas*, Vol. XVIII, No. 9.) Designed to meet the problem of winter peak loads exaggerated by war production demands, the California Railroad Commission has announced a plan to utilize the 240-acre Playa Del Rey depleted oil field near Venice, Calif., for the underground storage of surplus summer gas production. The gain in population and the increased demand for gas by war industries is threatening a serious shortage in the Los Angeles area during the coming months. Estimated peak demand in the winter is seen as 568,000,000 cu. ft. daily, with the available facilities yielding only 552,000,000 cu. ft. daily. Standby plants can produce 100,000 additional cu. ft. daily, but these are needed to equate the hourly demand. Under the plan proposed by the Commission, the Federal Government would take over the Playa Del Rey field and arrange for surplus gas from the other fields in California to be pumped into the underground reservoir. It is estimated that if this plan were followed in the remaining warm months, sufficient gas would be accumulated to permit daily withdrawals of 20 to 25 MM c. f. daily during cold spells.

R. H. O.

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